STICHTING VOOR BODEMKARTERING
WAGENINGEN

TANA DELTA IRRIGATION PROJECT

SEMI-DETAILED SOIL SURVEY

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Netherlands Soil Survey Institute
Staringgebouw
Wageningen

Report no. 1627

TANA DELTA IRRIGATION PROJECT
SEMI-DETAILED SOIL SURVEY

J. Stolp

Wageningen, february 1982

TANA DELTA IRRIGATION PROJECT

De Stichting voor Bodemkartering heeft een drietal bodemkarteringen uitgevoerd in het deltagebied van de Tana rivier in Kenya. Dit bodemkundig onderzoek vond plaats in opdracht van het Ingenieursbureau HASKONING BV te Nijmegen, die een feasibility studie verrichtte voor de Tana and Athi Rivers Development Authority (TARDA) naar de verbouw op grote schaal van geirrigeerde rijst.
De resultaten van het bodemkundig onderzoek zijn als afzonderlijke deelrapporten in deze studie opgenomen. Door de Stichting voor Bodemkartering zijn aan het Ingenieursbureau de volgende rapporten uitgebracht.

1. Stolp, J. and J.J. Vleeshouwer. 1981. Tana Delta Irrigation Project. Reconnaissance Soil Survey, Soil Survey Institute, Wageningen. Report no. 1609.

   Dit rapport is verwerkt in het Interim Report dat door de opdrachtgever aan TARDA is uitgebracht. De kaartbijlagen bij dit rapport zijn alleen aanwezig in de bibliotheek van de Hoofdafdeling Karteringen bij de Stichting voor Bodemkartering.

2. Stolp, J. 1982. Tana Delta Irrigation Project. Semi-detailed Soil Survey. Soil Survey Institute, Wageningen. Report no. 1627.

   Dit rapport + kaartbijlagen is opgenomen als Annex 1 in Volume II van de Feasibility Study TANA DELTA IRRIGATION PROJECT, door Haskoning BV en Mwenge IALtd uitgebracht in oktober 1982 aan de Tana and Athi Rivers Development Authority, Republic of Kenya. De kaarten zijn door de Stichting voor Bodemkartering in concept aan de opdrachtgever afgeleverd, die voor verdere afwerking heeft zorggedragen.

3. Stolp, J. 1983. Tana Delta Irrigation Project. Semi-detailed Soil Survey (Extension). Soil Survey Institute, Wageningen. Report no. 1700.

   Dit rapport is opgenomen in Chapter 1 (Soil Survey) in Volume I van de Feasibility Study - TANA DELTA IRRIGATION PROJECT (EXTENSION) dat door de bij rapport nr. 1627 genoemde Consultants in augustus 1983 aan TARDA is verstrekt. Een exemplaar van deze Feasibility Study ligt ter inzage bij de afdeling Ontwikkelingssamenwerking van de Stichting voor Bodemkartering.

REPUBLIC OF KENYA
TANA AND ATHI RIVERS DEVELOPMENT AUTHORITY

FEASIBILITY STUDY: VOLUME II

ANNEX 1: SOIL SURVEY

OCTOBER 1982

HASKONING
ROYAL DUTCH
CONSULTING
ENGINEERS AND
ARCHITECTS

MWENGE
INTERNATIONAL
ASSOCIATES LTD.

PREFACE

Within the context of a National Food Policy the Government of Kenya wishes to develop an irrigated rice farm of 10,000 ha in the Delta of the Tana River. As the Delta is flooded twice a year, adequate measures have to be taken to protect the irrigation areas.

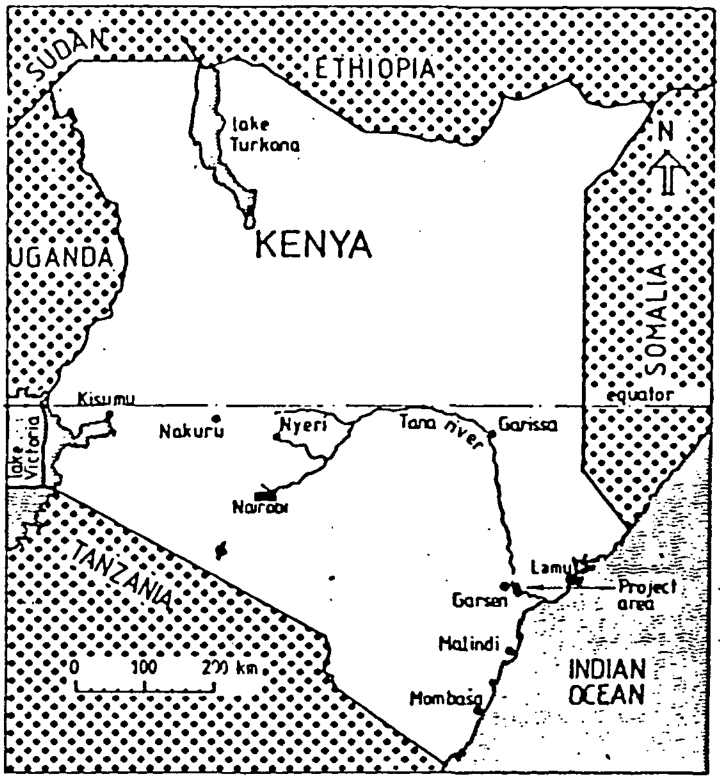
During the years 1981 and 1982, a detailed feasibility study was carried out, in which technical, ecological, sociological and economic aspects of the irrigation project are analysed and evaluated.

Various considerations and constraints, such as soil suitability, topography, flood diversion and existing network of natural drainage channels, river morphology, irrigation layout, ecological interface and mechanized farming, have led to a design of three separate irrigated rice polders, each of them enclosed by flood embankments.

The Final Report consists of nine volumes.

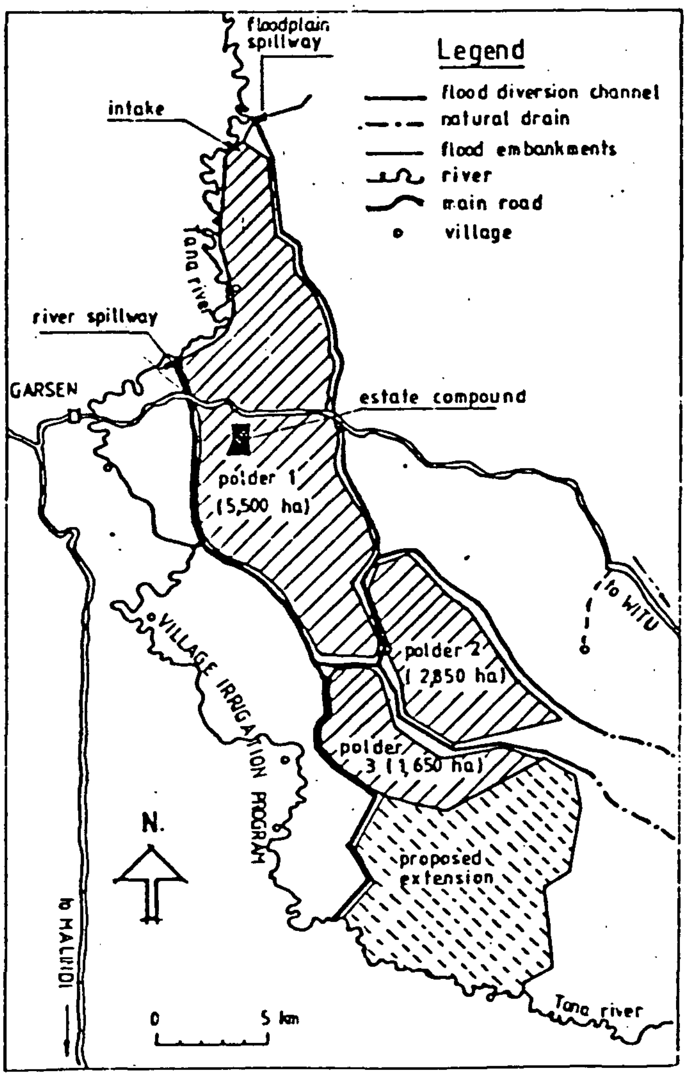
This volume (no. II) contains :

Annex 1 : Soil survey



<u>LOCATION PROJECT AREA</u>

<u>AND LAY-OUT</u>



THIS FEASIBILITY REPORT CONSISTS OF THE FOLLOWING VOLUMES AND ANNEXES

VOLUME I	Main Report
VOLUME II	Annex 1 : Soil survey
VOLUME III	Annex 2 : Hydrology
	Annex 3 : River morphology
	Annex 4 : Floodplain hydraulics
VOLUME IV	Annex 5 : Irrigation, drainage and flood control
VOLUME V	Annex 6 : Agronomy
VOLUME VI	Annex 7 : Farm mechanization
	Annex 8 : Agro industries
	Annex 9 : Organization and management
VOLUME VII	Annex 10: Infrastructure
	Annex 11: Estate compound
	Annex 12: Implementation schedule
VOLUME VIII	Annex 13: Animal husbandry
	Annex 14: Environmental interface
	Annex 15: Socio economics
VOLUME IX	Annex 16: Economic and Financial analysis

SOIL SURVEY

TANA DELTA IRRIGATION PROJECT

VOLUME II

ANNEX I : SOIL SURVEY

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PREFACE

A semi-detailed soil survey in the Tana Delta area was carried out in the period September-October by the Netherlands Soil Survey Institute at the request of Haskoning B.V. Consulting Engineers and Architects, Nijmegen.

This soil survey was made within the framework of the feasibility study of the Tana Delta Irrigation Project. Haskoning B.V. received the assignment for this project from the Tana River Development Authority. The investigation covered an area of approximately 11,000 ha, selected on the basis of the results of a reconnaissance soil survey in March 1981.

The soil survey team consisted of J. Stolp (team-leader), M. Bannink, G. van der Veen and J. Vrielink. A junior agronomist, M. van Tongeren, employed by Haskoning, joined this team.
J.J. Vleeshouwer (project leader) visited the team during the last week of September.

The cooperation and assistance of the Kenya Soil Survey and of local authorities in the area is much appreciated. Special acknowledgment is due to F.N. Muchena (Head of Kenya Soil Survey), B.J.A. van der Pouw and H.M.H. Braun (Soil Survey Specialists of the Kenya Soil Survey), O.O. Oswago (Tana River Development Authority, Soil Specialist) and Th.M. Kloppenburg (Lower Tana Village Irrigation Project, Minjila Hill).

The Director,

R.P.H.P. van der Schans

SUMMARY

The area covered by the semi-detailed soil survey for the Tana Delta Irrigation Project is situated in the southern part of the Tana River District in the Coast Province of Kenya. It is mainly located in the floodplain of the Tana River, roughly extending 11 kilometres north and 18 kilometres south-east of the all-weather Garsen-Witu road (Fig. 2.01). The total area presented on the soil map is approximately 15,600 ha. It includes an area of approximately 10000 ha selected for the envisaged project during a previous reconnaissance survey.

Much of the survey area is seasonally flooded and more or less subject to sedimentation of Tana River sediment; this are is indentical to the physiographic unit Floodplain. A second physiographic unit is Terrace land, comprising the higher lying, non-flooded areas with soils developed on old alluvial sediments.

The Floodplain consists of river levee land and river basin land.

The general pattern of the soils is shown on the soil map (MAP 1.01). Soils in the river levee land consist in general of a complex of deep, usually stratified, and highly variable soils with textures ranging from sand to clay. Four different major soil units are distinguished, mainly on the basis of differences in texture and topographical position. Additional information about relief, salinity and vegetation is given when relevant.

Soils in the river basin land are usually uniform and consist of strongly cracking clay in the top metre. The soils are first grouped according to differences in sedimentation in:

1. deep basin soils (7,650 ha)
2. basin-over-levee soils (1,010 ha)
3. basin-over-terrace soils (460 ha)
4. basin soils association (140 ha)

Each group consists of one or more major units because of a division over three classes of drainage conditions; moderately well to imperfectly drained, imperfectly drained and poorly drained. The poorly drained area covers approximately half of the area. A total of nine major units are distinguished which, for the top metre, have in common that they are:

- non-calcareous
- neutral to moderately alkaline soil reaction.

The bulk of the soils in river basin land is non-saline to a depth of at least 1 metre or more or, slightly saline from 70-80 cm onwards (8,330 ha). Salinity data of soil samples at depths of 110 cm and 160 cm and of the groundwater indicate that salinity usually increases considerably with depth (MAP 1.03).

In general the exchangeable sodium percentages are below 6 in non-saline horizons, though they are higher when soils become more saline with depth. Slight to moderate saline horizons usually have a relatively high ESP.

Soils of the Terrace land are grouped in three major units. Soils in the transition to the floodplain and low lying "black" soils are of interest to the project. The subsoil of the first unit however has a high degree of sodicity. This soil material has a low structure stability under wet conditions. Due to the clayey nature, and swelling characteristics, the soils in river basin land have slow infiltration rates when wet. The hydraulic conductivity is also low.

The soils have been appraised for large-scale irrigated rice. The criteria applied in the land evaluation procedure are summarised in Table 5.01, with assumptions concerning irrigability, drainability and prevention of salinisation (Chapter 5.2). Each soil mapping unit is evaluated separately and the results are presented in Table 5.04. A land suitability map is presented as MAP 5.02. The results can be summarised as follows (Table 5.03).

Land suitability for rice

Suitability class	Description of class	Limitations	Area (ha)
1	highly suitable	none to minor	7910
2	moderately suitable	slight to moderate	1100
3	marginally suitable	moderate to severe	1380
NS	unsuitable	-	5280

1 INTRODUCTION

1.1 General

The Tana Delta area is usually flooded twice a year, in May/June and November/December. During these times the perennial Tana River overflows the levees or breaks through its banks. Lower lying basin lands are inundated to depths of up to a metre or more. Crops, including rice planted with the receding flood, are grown along the riverbanks. In total, less than one per cent of the land area of the floodplain is cultivated. A great deal of water is not used. In view of the great need for areas that can supply large amounts of flood for the increasing number of people in Kenya, the Tana Delta area is likely to be of much interest for rice production.

The Tana River Development Authority (TRDA) felt the need of an inventory of the soil resources in the Tana Delta area and requested a soil survey within the framework of the feasibility study of the Tana Delta Irrigation Project.

In September and October 1981 a soil survey team from the Netherlands Soil Survey Institute carried out the field work for the semi-detailed survey in an area of approximately 11,000 ha, selected on the basis of data collected during a reconnaissance soil survey (Chapter 4.1). The semi-detailed survey had to be extended over a larger area because of the scattered nature and the rough delineation of the areas which were classified as highly suitable for large-scale rice cultivation during the reconnaissance survey.
For reasons of map presentation unsuitable areas are also included. The total area presented on the maps therefore covers approximately 15,600 ha. However, the main investigation was concentrated on the selected areas.

1.2 Terms of Reference

The consultants proposal for the semi-detailed soil survey was considered to follow the general norms and practices for such a survey (Siderius, W., 1980). It stated that a soil survey at semi-detail level would be undertaken on - at least - 10,000 ha of an area delineated after the reconnaissance survey.

The semi-detailed survey was to be carried out using a map scale of 1:25,000. The base maps would be derived from an "uncontrolled mosaic", scale 1:25,000. The inspection density would be one observation per

15-20 hectares. Augering was to be done down to 200 cm and samples taken at five depths (20, 40, 70, 110 and 160 cm depth) for determination of pH and electrical conductivity (EC) in a 1:2.5 (soil:water) suspension.

Representative profile pits in major soil mapping units were to be made to a depth of 2 metres and augered to 5 metres, as far as soil conditions permit. Soil samples were to be taken from the representative pits and submitted to the National Agricultural Laboratories (NAL) for analysis. Permeability tests and infiltration tests were to be carried out at approximately 10 selected sites. Subsoil investigations were to be carried out to a depth of 5 metres, if soil conditions would allow, with a density of 1 out of 20 soil survey observations. Soil profile pits with augering down to 5 metres were included in these subsoil investigations to approach this density. After completion of the survey all original field notes were to be submitted to Kenya Soil Survey (KSS).

1.3 Survey objectives

The objective of the semi-detailed soil survey was to collect and evaluate data on the soil conditions of the 10,000 ha and to determine the suitability for large-scale irrigated rice.

The investigations resulted in a soil map and a land suitability map for large-scale irrigated rice. This report gives further information on the physical environment, methods applied and comprehensive descriptions of the soil mapping units, including physical and chemical characterization. It furthermore gives a short account of procedures and physical criteria used in the land classification.

2. LOCATION, GEOLOGY, HYDROLOGY AND GENERAL LAND FEATURES

2.1 Location and communications

The Project Area is situated in the southern part of the Tana River District and a very small part in the Lamu District, both in Coast Province. It lies between latitude 2° 28' S, and longitude 40° 20' E.

The area extends from Sailoni, in the north, to roughly a west-east line over Ngao up to the Abarfarda, south of Moa. The western boundary is the Tana River from Sailoni to Hewani, from there following the former Tana River course (Mitapani) as far as Gomessa in the south. The eastern boundary is mainly the border of the usually slightly higher lying Terrace land (Chapter 2.2). South of the Garsen-Witu road the boundary coincides with a straight line from the bridge over the Lango la Simba to a point approximately 3 km south of Moa village (Fig. 2.01).

The survey area is traversed by a road from Garsen to Witu/Lamu. This road is an all-weather road, though difficult to drive on after rainy periods. Apart from this there are only tracks, mostly without any surfacing. Traffic by car during the rainy seasons is limited or even impossible on these tracks.
The track to Hewani/Wema, extending northwards from the turn-off at the all-weather road is maintained by the Ministry of Transport and Communication, Department of Roads, with a grader, but only as far as Wema. It permits car traffic up to that village. Other tracks which connect the several villages in the area are mainly foot paths and in some places car traffic is not possible during the rainy seasons or for some time after the flood has receded. These tracks are usually concentrated on the higher lying areas (levee land) near the Tana River or its former courses, for instance the Mitapani. There are hardly any tracks in the basin land. The few tracks there, near Galili and Onkolde (Orma villages), are predominantly made and used by cattle, walking each day from the village to the grazing areas and back again.

Cutlines occur in the adjacent area, east of the project area. They were prepared for a Shell-BP oil exploration programme in about 1960. They are not used by the local people and in certain places have become overgrown. As no villages, except for Moa, are present in the eastern part of the area, these cutlines are the only motorable tracks that connect this part of the area with the all-weather road. High speed is frequently impossible because of many elephant prints.

2.2 Geology, hydrology and general land features

In geological reports the delta area of the Tana River is mapped as recent alluvium with bands of older sand and clay ridges. The survey area consists largely of recent fluviatile deposits of the Tana River; sand, silt and clay sedimentated during the biannual flooding.

The bands of older sand and clay ridges, that were deposited during various oceanic phases (Tertiary, Holocene) and becoming progressively younger towards the coast, border the recent alluvial plain. Because of their slightly higher elevation they are indicated here as Terrace land*. The eastern boundary of the surveyed area coincides with the transition from the recent floodplain to this Terrace land. Sediments of this Terrace land are also found in the surveyed area, in Terrace inliers (remnants of erosion processes) or in the subsoil. The latter are covered by recent fluvial sediments. The Terrace material usually consists of sandy clays to clays which are predominantly saline and sodic.

The recent fluvial deposits, being the main parent material for the soils in the surveyed area, are predominantly non-saline and non-sodic within 100 cm depth. Deeper than 100 cm salinity increases to strongly saline in places.

The physiography of the Tana Delta is presented in Figure 2.02. The survey area for the Tana Delta Irrigation Project is largely situated in the recent floodplain of the Tana River. The two main physiographic units are River basin land and River levee land. Another main physiographic unit is Terrace land, occurring as the adjacent higher lying area and as higher lying inliers in the floodplain. Figure 2.03 gives a cross section through the Tana Delta and the relation between physiography and major soil units. In the northern part of the area the recent Tana River levee land is considerably higher than the adjacent basin land at the east side.

At several places the Tana River has breached through the natural levee, but has subsequently resumed its original course. The relating deposits of these crevasse splays (or floodplain splays) are found in the adjacent parts of the plain in small levees.

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* The use of the term Terrace is a restricted one here. In principle this denotation should not be confined to higher lying alluvial areas. The recent fluviatile plain may be considered to be a terrace too.

The former gully in this splay is often still distinguishable. In the village of Wema the houses are built on the borders of such a former gully. The other villages are also located on these crevasse splays deposits.

Near Hewani, the Tana River flows in a south-westerly direction to Garsen. According to verbal information of local inhabitants the main course of the Tana River up to about a century ago was running from Hewani in a southerly direction. The levees of this former course, called the Mitapani River for convenience, are also considerably higher than the adjacent basin land in the project area, east of it.

The former course is still present as a deeply incised river bed through which water is transported only in the flood season. At the end of the dry season large parts of it are completely dry. In the Mitapani River levee land cut-off meanders are present, some of them as oxbow lakes. Point bars are also a common feature. Except for these features, which are confined to the former activity of the Mitapani River, other drainage ways are also present. These are a few gullies that connect the meander-belt area of the Mitapani River, through its levee, with the basin area. Floodwater flows through these gullies into the basin area. They also act as drains when the floods recede.

Crevasse splays, as described for the Tana River levee land north of the Garsen-Witu road, are also distinguished in the Mitapani river levee land. One large and complex area of crevasse splays occurs approximately one kilometre south of the Garsen-Witu road. Several hundred metres north of this area an elongated crevasse splay is present*.

These areas and also the higher lying surrounding areas are used for temporary settlement. The villages of Onkolde and Galili, more to the south, are also situated on crevasse splays (Fig. 2.04). The crevasse splay of Gomessa village in particular shows the considerably higher position in the landscape. The difference in altitude with the near-by basin land is 1.5 to 2 metres. Sinkholes are a common feature in the areas of crevasse splays. They also occur in the Mitapani River levee land, in particular in the vicinity of former river courses.

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* These areas are mistakenly indicated as areas belonging to the Terrace land with mapping symbol TOu in the reconnaissance soil survey.

South of Galili, near Gomessa, the major part of the levee land of the Mitapani River extends southwards. In this area a deeply incised gully connects the Mitapani River course with the basin land east of it (Fig. 2.05). Near Gomessa a cut-off branch of the Mitapani River, or the older course of the Mitapani River, continues in a south-easterly direction.

It has built up a natural levee whose extent decreases with increasing distance from the beginning. Crevasse splays of minor importance can be distinguished, sinkholes are almost absent. This river course, called Abarfarda River for convenience, has a notable eastern direction ove a length of approximately eight kilometres. The Abarfarda River then continues in a south- easterly direction. This river has developed large meanders, the meander-belt however shows no cut-off meanders (e.g. oxbow lakes). The related deposits are in general fine textured, indicating a relatively low carrying capacity for sand/silt, when the river was acting as a perennial river. The river course is still present though partly filled in and overgrown by brook forests.

Another former part of the Tana River system is the Lango la Simba system in the eastern part of the project area. Though a former Tana River course, there is no longer any visible connection with the recent Tana River system. In the area north of the Garsen- Witu road an almost completely silted up river course can be distinguished. It extends from the forest, east of Hewani, in a south-easterly direction to the Lango la Simba bridge on the Garsen-Witu road. North of the forest the river course has almost disappeared because of silting up.

The Lango la Simba is important for the transport of the floodwater flowing into the basin area in the vicinity of Sailoni and for the transport of the excess rainwater from the Terrace land. Approximately one kilometre north of the bridge the course of the Lango la Simba is clearly visible, the related natural levee however is small or absent. South of the bridge the river levee land of the Lango la Simba is more or less covered with clay (basin clay). The Lango la Simba meanders are silted up to some extent. Unlike the Mitapani River the Lango la Simba shows many deeply incised gullies which cut off and connect the meanders. The Lango la Simba therefore is to be considered as a gully drainage way for excess flood-water.

The extent of the river levee land of the Lango la Simba decreases from north to south. In the area south-east of Galili the deposition of (basin) clay has covered the levee sediments and soils are mapped as basin-over-levee soils.

The River basin land is either enclosed by the above mentioned river levee lands or is found between the river levee land and the adjacent Terrace land. The basin lands are inundated by the annual floods for a variable duration and to a variable depth, depending on the topographical position. The soil consists of heavy clay with often more than 50 per cent of the particle size fraction less than two microns.

The area adjacent to the river levee land is moderately high lying, flooded for a short time or shallowly inundated though not with each flood. Gullies or drainage ways are usually absent in these areas, except for some major ones that connect the low basin area with the courses in the river levee land. In addition one can distinguish a moderately low lying area, exposed to flooding every year, but usually dry for a large part of the dry season except for small shallow depressions and gullies.

The central parts of the basin land are low and longest flooded, usually more than 80 to 100 cm. A network of shallow gullies and shallow depressions is present in most areas (Fig. 2.06). The shallow gullies run into wide, often not very deep gullies that ultimately run into a river course or major gully.

The soils of the basin land consist predominantly of clay (to 2 m depth); deep basin soils. At the transition to the Terrace land in the south-eastern part of the project area the basin clay is deposited over Terrace material (basin-over-terrace soils).

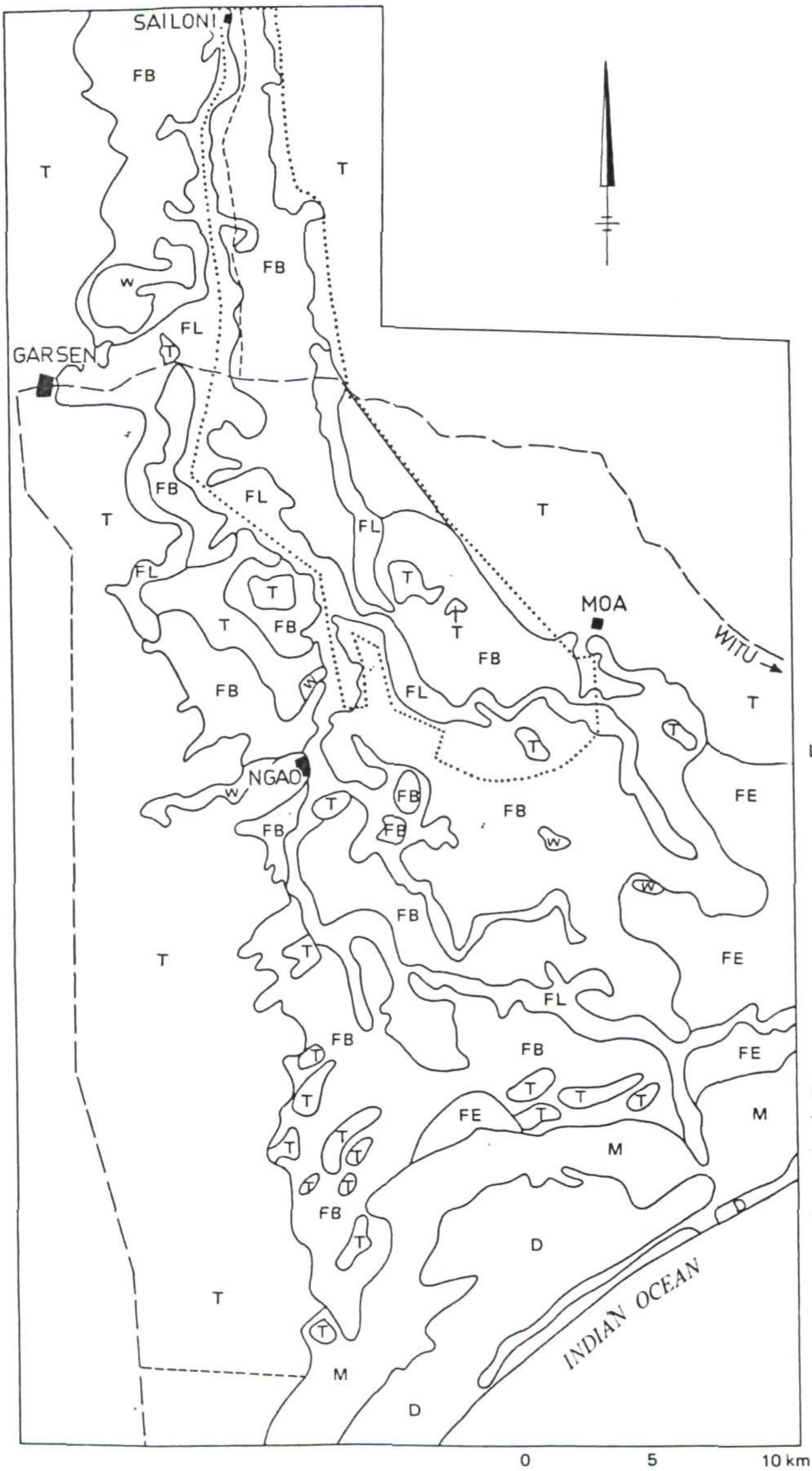
Also in the south-eastern part of the project area basin clay is sedimented over levee material: basin-over-levee soils. The area with the levee-subsoil starts from the Lango la Simba levee land approximately three kilometres north-east of Galili and continues in a south-easterly direction.

The levee-subsoil area of the western branch of the Lango la Simba along Galili joins the above mentioned basin-over-levee area approximately two kilometres north of the Abarfarda River course. From there a shallow, meandering old river course in a southerly direction indicates the area with the levee-subsoil.

South of the Abarfarda levee land the basin land is, as far as is known, part of an extensive plain without major river systems. It appears as the transition from the fluviatile to the more estuarine area. In some places small gullies are present, filled up with sand and usually covered with clay up to 30 cm thickness.

Adjacent to the gullies the typical basin clay profile is present on a slightly higher level.

The Terrace land in the area north of the Garsen-Witu road borders the low basin area; south of the road it joins the Lango la Simba levee land for approximately five kilometres. From the place where the levee-subsoil starts, the transition form the basin land to the Terrace land is vague and relies more on properties of the soil (old alluvial-sodic material at shallow depth) than on geomorphological features.



LEGEND

FL river levee land

FB river basin land

FE estuarine basin land

M coastal marshes and swamps

D dunes and recent beach ridges

T terrace land, bottom land and lagunal sandridges

KEY

— — main road

- - - - track

w permanent water

.... *boundary of semi-detailed soil survey*

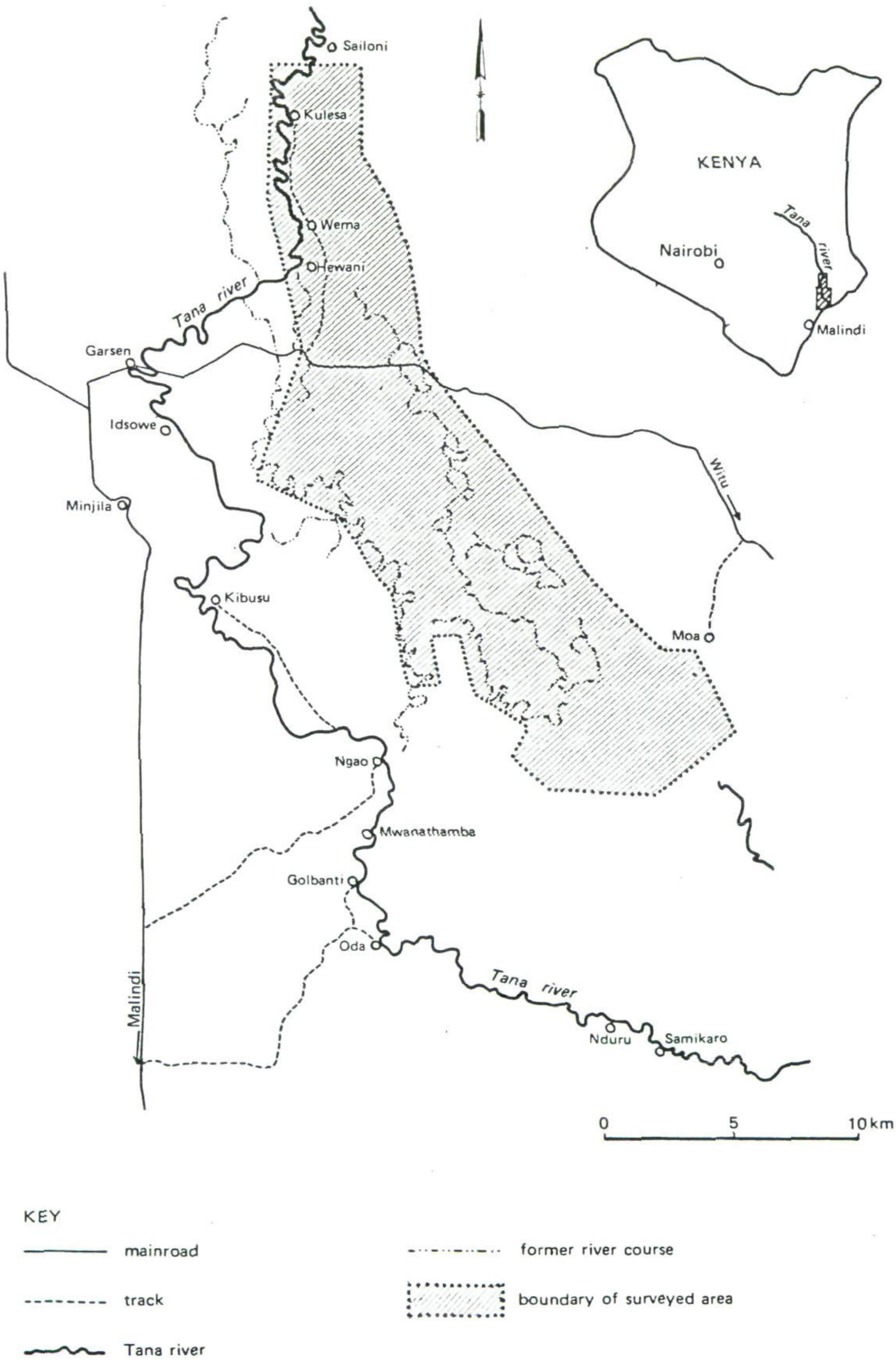
HASKONING BV

Mwenge International Associated Limited

fig: 2.02

title:

PHYSIOGRAPHY OF THE TANA DELTA



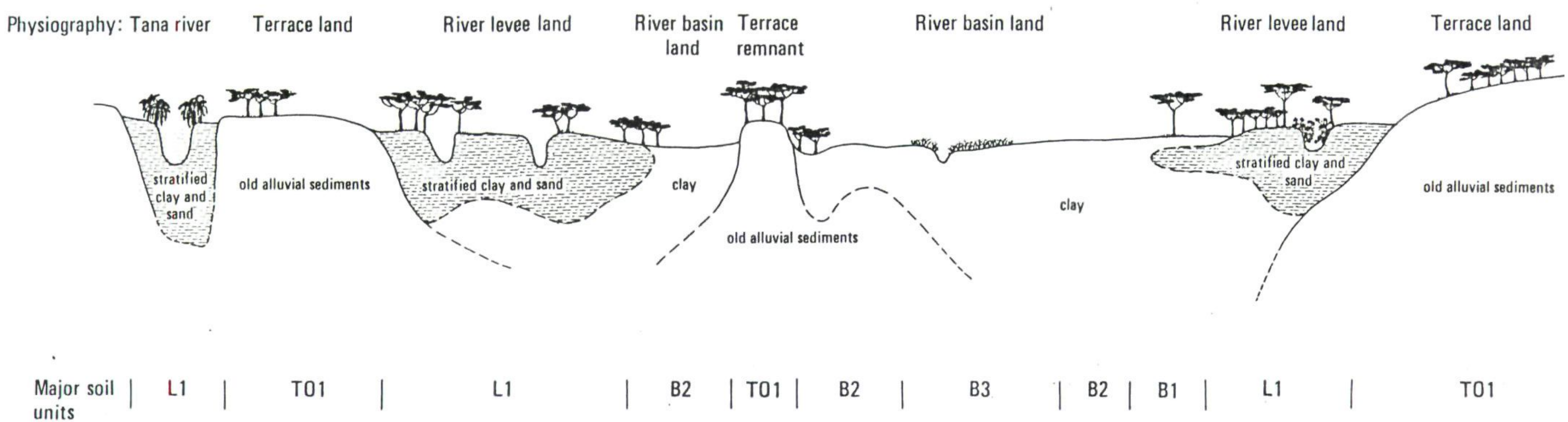
HASKONING BV

Mwenge International Associated Limited

fig : 2.01

title :

LOCATION OF THE AREA OF THE SEMI – DETAILED SOIL SURVEY



HASKONING BV

Mwenge International Associated Limited

fig: 2.03

title: SCHEMATIC CROSS-SECTION THROUGH THE TANA DELTA AND THE RELATION BETWEEN PHYSIOGRAPHY AND MAJOR SOIL UNITS

Fig. 2.04 Part of the Orma village Galili

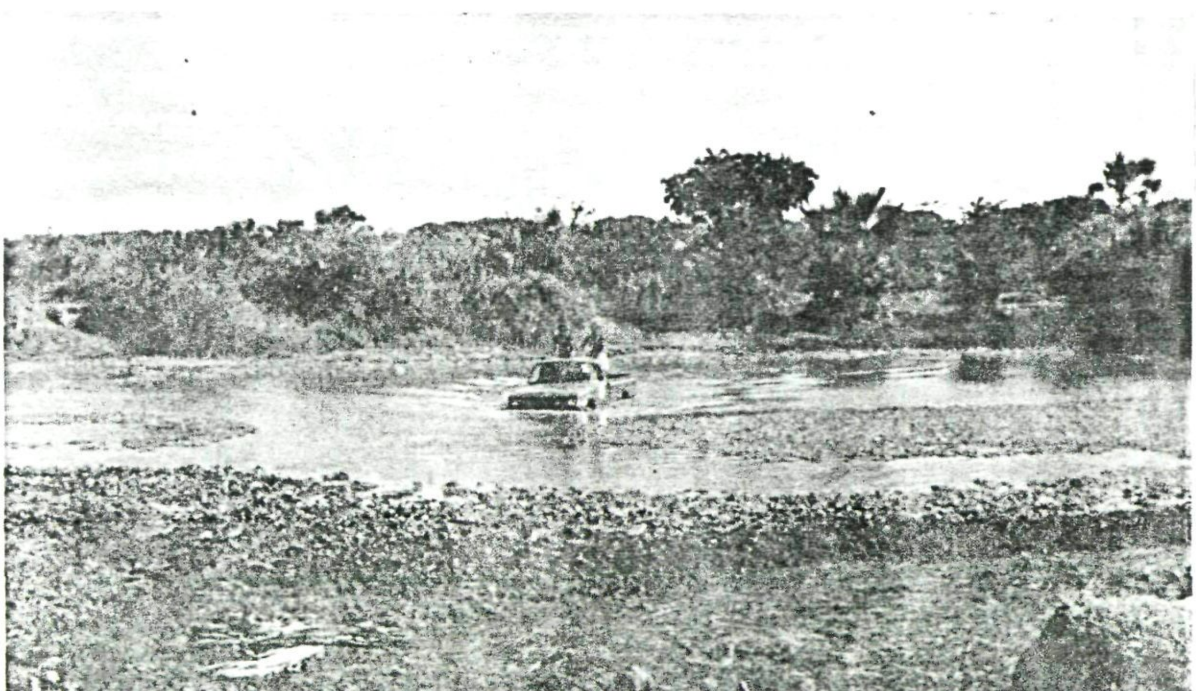


Fig. 2.05 The gully from the Mitapani river course to the basin land, south of Galili is difficult to cross by car

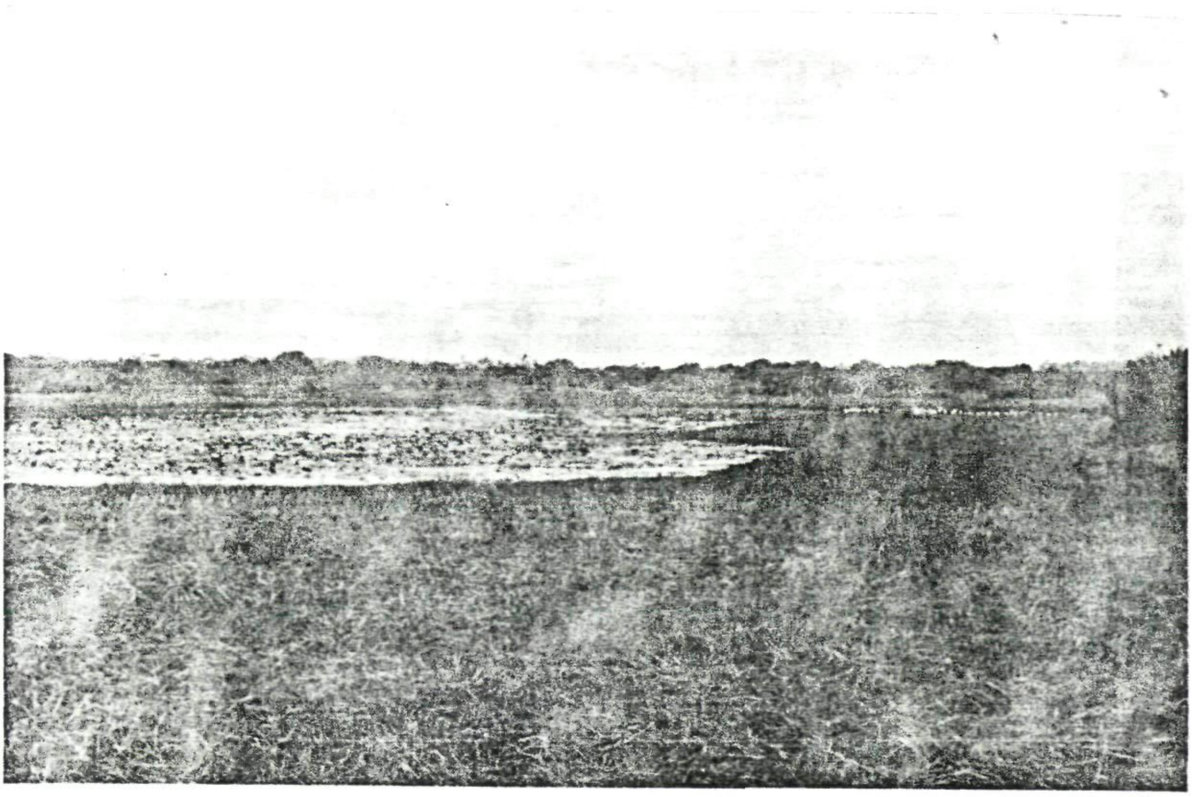


Fig. 2.06 Shallow depression in river basin land; reliefclass II

3. METHODS OF INVESTIGATION

3.1 Office methods

Reports and maps of the reconnaissance survey of the Tana Delta (Haskoning and Mwenge IAL, 1981) were the main source of information about soils in the project area. All data collected for that survey were used if relevant.

Prior to the fieldwork, aerial photographs, scale 1:45,000 (Geosurvey, 1980), were enlarged to scale 1:25,000 and an uncontrolled photo mosaic was composed.

The area to be investigated, was broadly outlined on a photo mosaic before the start of the fieldwork. The enlarged aerial photographs proved to be very useful in the field for accurate location and for plotting the observations and soil boundaries. During the fieldwork all observations and boundaries, seen in the field, were transferred to a photo mosaic. A stereoscopic study of the aerial photographs, scale 1:45.000, was carried out periodically to support the fieldwork and to adjust the soil boundaries on the photomosaic.

After completion of the fieldwork a draft base map was prepared, making use of the uncontrolled photo mosaic, as no topographic map on the scale 1:25,000 was available.

Roads, tracks, villages, the Tana River and its former courses and other topographical features like gullies and other drainage ways observed in the field, were outlined on this base map. At the same time the data concerning salinity, measured by means of electrical conductivity of 1:2.5 v/v samples in the field laboratory were incorporated in the soil map on the photo mosaic. Then the final soil boundaries and symbols were transferred to the base map on the scale 1:25,000. This resulted in a final soil map. This map was used to outline the suitability classes for large-scale irrigated rice.

A "salinity" map was prepared, using the base map to represent the salinity classes of the soil, sampled at depths 110 cm and 160 cm. The real value of the salinity of the groundwater, if encountered, in EC (mS/cm) was also noted on this map.

3.2 Field methods

The actual fieldwork was carried out in September and the first week of October, 1981. The fieldwork was executed from an encampment, stationed at Minjila Hill, close to the compound of the Department of Agriculture. By courtesy of the manager of the Lower Tana Village Irrigation Programme, at Minjila Hill, the field laboratory and the fieldoffice could be set up in one of their buildings. The investigations were carried out by several teams, viz. soil survey, field physical tests and laboratory.

Fieldwork comprised routine augering by hand to a depth of 200 cm at intervals of 300 to 400 metres in a pattern, mainly conditioned by the accessibility of the area. One out of approximately 30 augerings was continued to a depth of five metres, soil conditions permitting. At the start of the survey the lower basin areas were still inundated and not accessible by car. Therefore this area was surveyed after the water had either evaporated or drained away. Some parts nevertheless remained inundated and had to be surveyed on foot. Some gullies that could not be crossed by car, also necessitated such a survey. At each augerhole soil samples were taken at specific depths, viz. 20, 40, 70, 110 and 160 cm, for screening tests in the field laboratory at Minjila Hill (pH, EC and degree of dispersion).

If groundwater was encountered within a depth of 200 cm, a water sample was taken for tests in the field laboratory.

Representative sites were selected in major soil units and 150-200 cm deep profile pits were dug. The pits were subsequently augered up to a depth of five metres, soil conditions permitting. These pits were described and sampled for later chemical analysis at the National Agricultural Laboratories.
Composite samples of the topsoil (usually 0-20 cm) were taken for fertility evaluation. Land and soil properties were recorded on standard soil augerhole and soil profile pit description forms, following the standards applied by the Kenya Soil Survey which are based on the "Guidelines for soil profile description (FAO, 1977). A total of 740 augerings were made and described. Furthermore, data of 21 profile pits were collected. Infiltration tests and hydraulic conductivity tests were carried out at the selected sites for the major soil units where profile pits were dug. The sites were selected in locations where the soil was very moist near-by. Infiltration and hydraulic

conductivity tests were carried out under moist to wet conditions of the soil and the results must be considered in this respect. The hydraulic conductivity tests were carried out on the layers at a depth of 30-100 cm. The methods applied are described in Chapter 4.7.

Field Laboratory

In the field laboratory at Minjila Hill the electrical conductivity (EC) and pH of approximately 3950 samples from augerings and profile pits were determined in a soil: water suspension of 1:2.5. These samples were taken at 20, 40, 70, 110 and 160 cm depths as a routine. Additional sampling of the profile pits occurred according to the described soil horizons. EC and pH of groundwater were measured in undiluted samples.

The 1:2.5 suspensions were prepared in standard size, small tubes with two marks, one at 2½ volume level and another one at 3½ volume level. The tubes were filled with deionized water up to the first mark giving 2½ volume water. In the field crushed soil aggregates were added until the level of the suspension reached the 3½ mark, thus resulting in a soil:water ratio of 1:2.5 (volume/volume). The samples were thoroughly shaken after one day field survey. After standing overnight in the field laboratory, EC and pH were measured in the clear solution above the suspended soil. The degree of suspension was determined by measuring the height of the suspension of the tube. If no clear solution was available, another 2½ volume deionized water was added, the suspension shaken and set aside for one day to settle.

The soil aggregates added to the dionized water in the field were moist with very little or no air enclosed in them. A few experiments were carried out to determine the average moisture percentage of the material in the field, the 1:2.5 v/v samples and of the saturated soil pastes. This resulted in a conversion factor for the electrical conductivity values (see Chapter 4.6.2). The equipment of the field laboratory allowed only a rather rough approach as the oven necessary for drying was not available.

3.3 Laboratory methods

75 soil samples and 13 fertility samples were taken from 15 representative profile pits and delivered to the National Agricultural Laboratories (NAL), Nairobi. N.A.L. employs the following methods:

Sample preparation	: Breaking up of aggregates by careful pounding with pestle and mortar; sieving through a 2 mm sieve. The fine earth fraction (less than 2 mm) is used for further analyses.
Texture (hydrometer)	: No chemical treatments to remove cementing agents, shaking overnight with sodium hexametaphosphate/sodium carbonate in an end-over-end shaked at 40 r.p.m. Measurement of silt+clay (0-50) and clay (0-2) with a hydrometer ASTM 152H after 40 seconds and 2 hours respectively. Sand fraction (50-200) obtained by difference (Day, 1956)
pH-H_2O and EC	: pH and EC are routinely measured in suspensions with a soil: water ratio of 1:2.5. Suspensions are prepared by scooping up one volume of fine earth and adding it to 2½ volumes of water*. For samples with an EC greater than 0.8 mmhos/cm a saturation extract is prepared for additional pH and EC determination. Upon request the soluble salts in the extract are also measured.
pH-KCl	: Measurement in a suspension with a 1:2.5 ratio of soil: 1N KCl.
$CaCO_3$	: Gravimetric determination of loss of carbon dioxide (Richards, 1954).
$CaSO_4$	: Determination of gypsum is based on the low solubility in an aqueous solution of acetone. The separated and washed gypsum precipitate is determined quantitatively using a reference graph showing relationship between the concentration and electrical conductivity of gypsum solutions.
Carbon	: Walkley and Black method (Black, 1965 pp. 1372/6).

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* Loose, fine earth prepared for analyses is estimated to have a bulk density of 1.2 g/cm^3. By scooping up one volume of this fine earth and adding it to 2½ volume water, the weight/weight ratio of the soil:water suspension is about 1:2. Note the different method for the field laboratory measurements.

Cation exchange capacity	: CEC is determined by successive leachings of the soil with 1N sodium acetate of pH 8.2, 95% ethyl alcohol and 1N ammonium acetate of pH 7.0. Determination of Na in the last leachate by EEL flamephotometer.
Exchangeable cations	: Leaching of the soil with 1N ammonium acetate of pH 7.0. Determination of Na, K and Ca by EEL flamephotometer, with addition of lanthanum chloride for the last element. Mg is determined with an atomic absorption spectrophotometer.
"Mass Analysis" for available nunutrients (on composite topsoil samples)	: Extraction of the soil by shaking for one hour at a 1:5 ratio with 0.1NHCl/0.025N H_2SO_4. Determination of Ca, K and Na by EEL flamephotometer. Mg is determined colorimetrically with Thiazol yellow reagent (Mehlich et al., 1962). Mn is also determined colorimetrically using phosphoric acid-potassium periodate for colour development (Mehlich et al., 1962). For P, the vanadomolybdophosphoric yellow method is followed.

4. SOILS

4.1 Previous work

4.1.1 Site evaluation

A preliminary evaluation of the soil conditions of the Tana Delta for irrigation development was carried out by the Kenya Soil Survey (Wokabi et al., 1976). A map, scale 1:100,000, was prepared mainly on the basis of aerial photo interpretation and supported by a limited number of field observations.
The areas of river basin land, comprising about 38,000 ha, were considered "moderately well suited" for irrigation. The soils were described as "deep, non-calcareous, heavy clay soils that are usually non-saline and non-alkaline".

4.1.2 Reconnaissance soil survey

A reconnaissance soil survey was carried out in the Tana Delta by the Netherlands Soil Survey Institute, 1981, to investigate in more detail the river basin land for the selection of areas, feasible for the development of large-scale rice cultivation (Haskoning and Mwenge IAL, 1981). The total area for the reconnaissance survey extended over approximately 63.500 ha. It included an area of 28,500 ha, for which the investigation consisted of the evaluation of existing data about soil and land due to a detailed-reconnaissance survey of this area (Grabowsky & Poort, 1980; Lower Tana Village Irrigation Programme). In the remaining area of 35,000 ha a survey was carried out with an inspection density of one observation per 150 ha in the river basin land and adjacent estuarine basin land. Few observations have been made in the surrounding river levee land and Terrace land. A photo interpretation map was checked and adjusted and soil samples were collected from augerings to 2 metres depth.
The acidity (pH) and degree of salinity were measured in the diluted soil samples (1:2.5 v/v).
Three major physiographic units were distinguished in the project area: Floodplains (41,500 ha), Terrace land (18,000 ha) and Former Beach Ridges (2,300 ha). The Tana River has eroded part of the Terrace land and has subsequently deposited recent fluvial sediments in the present delta: Floodplains. In the vicinity of the present outlet of the Tana River however these fluvial sediments overlie subrecent marine sediments, laid down in an estuarine environment.

Areas with a total extent of approximately 1,500 ha and consisting of both recent fluvial and old alluvial sediments (Terrace material) are indicated separately on the soil map as Complex Areas.

Each physiographic unit consists of several soil units. A description of each soil unit is given in Appendix 2; Table A2.1 - Legend of the reconnaissance soil map.

The soils of the Terrace Land are highly sodic and frequently saline. Soils of the Former Beach Ridges are coarse textured and often excessively drained. These soil qualities in Terrace land and Former Beach Ridges and, in addition, the location on relatively high lying areas are strong limitations for (gravity) irrigation of large-scale cultivated rice.

The soils of the Floodplains have more potential for rice production. Particularly the soils in river basin land (25,500 ha) which usually consist of heavy clay throughout, have high potential. Soils in river levee land (10,300 ha) have limitations because of deficiences in soil and land qualities. Also the soils, consisting of fluviatile sediment over subrecent marine sediments (5,700 ha), have potential, though low due to acidity constraints. The main land characteristics of the mapping units are summarized in Appendix 2; Table A2.2.

All soil mapping units were evaluated in behalf of the land suitability for large-scale irrigated rice. This evaluation implied an appraisal of soil and land qualities and subsequently the ranking of the mapping units in four suitability classes according to the severity of their limitations. The appraisal is carried out with the assumption that

- flood control works will be constructed to prevent the area from flooding;
- sufficient irrigation water of good quality will be made available to crop areas;
- adequate measures will be taken to drain excess rainfall and irrigation water (depending upon the crop calendar and related water duty);
- adequate measures will be taken to prevent salinization of soils during cultivation.

The result of the land suitability classification for large-scale irrigated rice is included in Appendix 2. Table A2.2 contains the acreage of each soil mapping unit and the corresponding suitability class.

The main results are summarized as follows:

(tabel plakken)

Class	Suitability for large-scale rice irrigation	Limitations	Area (ha)
1	highly suitable	few or none	24 200
2	moderately suitable	slight to moderate	1 500
3	marginally suitable	moderate to severe	3 200
NS	unsuitable	severe	34 600

Fig. 5.02 in Appendix 2 shows the spatial extent of the suitability classes by means of a generalized land suitability map.
The total area of class 1 soils is 24,200 ha. However a part of it consists of rather small patches. One large, continuous area is found north and south of the Garsen-Witu road, extending northwards to Wema and in a southerly direction to an east-west line approximately six kilometres south of Moa. South-east of this line, soils become saline at more shallow depth. The other large area is situated east and north-east of Ngao. In view of its extent and accessibility it was recommended that the 10,000 ha for the envisaged project should be selected in the area north and south of the Garsen-Witu road. The location of this area is indicated in Figure 2.01.

4.2 Soil classification

The soil classification is based on the FAO-Unesco Soil Map of the World Legend (FAO, 1974). Modifications introduced by the Kenya Soil Survey (Siderius and Van der Pouw, 1980) are employed when relevant.

All soils developed on recent alluvial sediments of the Tana River are classified in the group of the Fluvisols. This major soil group is subdivided into two subgroups; eutric and vertic Fluvisols. The latter consists of strongly cracking ("vertic") clay. Saline and sodic phases are indicated when applicable. The two major soil groups in the Terrace land are the Solonetz and the Vertisols. Two subgroups have been identified in the Solonetz; vertic and orthic Solonetz. The Vertisols here have a very dark gray to black topsoil; pellic Vertisols. Both saline and sodic phases occur.

4.3 Legend of the semi-detailed soil map

4.3.1 General

The soil mapping units are grouped according to their physiographic position in the field and the parent material on which they are formed. At the highest level in the legend the following physiographic units are distinguished: Floodplain (its extent restricted to the area that is flooded by Tana water) and Terrace land. The parent material in the Floodplain is characterized as recent fluviatile sediments, the parent material in the Terrace land is broadly described as old alluvial sediments. The latter presumably of marine/lacustrine origin.

Within the Floodplain the soils have been grouped into the landform that could be distinguished: river levee land, also including the crevasse splays (general code L), and river basin land (general code B). The soils of the river levee land are subdivided predominantly on the basis of the variation in texture, which is related to their morphological location (major units L1, L2, L3 and L4).

The soils of the river basin land are first divided on the basis of differences in sedimentation (Table 4.01; subgroups). A further subdivision in each subgroup is made according to the drainage conditions, which are closely related to the topographical position. The low lying basin soils for instance, are poorly to very poorly drained. The relationship implies that the topographical position is reflected more or less in the description of the drainage conditions. The subdivision of a subgroup results in major soil units. The codes for these major units are given in Table 4.01.

Table 4.01 Major units in river basin land

subgroup	codes major units
deep basin soils	B1, B2, B3
basin-over-levee soils	$\frac{B2}{L}$, $\frac{B3}{L}$
basin-over-terrace soils	$\frac{B1}{T}$, $\frac{B2}{T}$, $\frac{B3}{T}$
association of basin soils	B1/$\frac{L}{B}$

Additonal features are used to describe the salinity conditions, relief conditions and the vegetation type of the soils in each major unit. Salinity conditions are indicated, using a salinity profile classification (SO, S1, S2, S3 and S4), relief conditions are noted, according to relief classes (I, II and III) and the vegetation type is mentioned only if bushland or forest could be distinguished (b,f). The codes are explained in paragraph 4.3.2.

In summary: a unit on the soil map consists of the major unit code supplied by the salinity profile code, the relief class code and vegetation type code. The latter when applicable.

4.3.2 Differentiating criteria

Differentiating criteria, used in the legend and the descriptions of the mapping units and representative profiles are:

- Texture, structure and other characteristics e.g. concretions and consistence are described according to the "Guidelines for soil profile description" (FAO, 1977)

- Colour of the soils are described according to the Munsell Soil Colour Charts and the Japanese "Revised Standard Soil Colour Charts"

- Soil reaction. The following classes in soil reaction and the corresponding rates are used:

class	$pH\text{-}H_2O$ rate
extremely acid	<4.5
strongly acid	4.5-5.5
slightly acid	5.6-6.5
neutral	6.6-7.3
moderately alkaline	7.4-8.4
strongly alkaline	8.5-9.0
very strongly alkaline	>9.0

- Soil salinity. The following salinity classes and corresponding rates are used: (see also Chapter 4.6.2)

Salinity class	ECe (mS/cm)	EC (1 : 2.5 v/v)* (mS/cm)
non-saline	<4	<2
slightly saline	4- 8	2-4
moderately saline	8-16	4-8
strongly saline	>16	>8

* valid for moist material with a texture of clay

- Salinity profile. The sequence of salinity in a soil profile, measured at specific depths is classified as follows:

code	salinity class at specific depth (cm below surface)		
	20	40/50	70/80
S0	non-saline	non-saline	non-saline
S1	non-saline	non-saline	slightly saline
S2	non-saline	non-saline	moderately saline
	or non-saline	slightly saline	slightly saline
S3	non-saline	slightly saline	moderately saline
S4	non-saline	moderately/strongly saline	moderately/strongly saline

- Soil sodicity. The following sodicity classes and corresponding rates are used: (see also Chapter 4.6.3)

Sodicity class	ESP*
non-sodic	0- 5
slightly sodic	6-10
moderately sodic	11-15
strongly sodic	>15

* Due to the lack of sufficient ESP data of analysed samples the description of the soil sodicity is limited often to an indication of non-sodic or sodic.

- Infiltration rate. The following classes in infiltration rate and the corresponding rates (I-basic) are used: (see also Chapter 4.7.2)

Infiltration class	rates in mm/hr
very slow	<0.5
slow	0.5- 4
moderately slow	4-10
moderately rapid	10-20
rapid	20-40
very rapid	>40

- Hydraulic conductivity. The following hydraulic conductivity classes and corresponding rates are used: (see also Chapter 4.7.3)

hydraulic conductivity class	rates in cm/day
very slow	<3
slow	3- 10
moderately slow	10- 20
moderate	20- 40
moderately rapid	40- 80
rapid	80-160
very rapid	>160

- Relief class. The following relief classes on basis of meso- and microrelief features are used:

Code	description
I	mesorelief : predominantly flat; few shallow depressions microrelief : smooth except for gilgai and sinkholes
II	mesorelief : flat to very gently undulating; wide network of shallow depressions microrelief : smooth except for gilgai, small (sedge-) tussocks and cowfoetoes
III	mesorelief : very gently undulating, in places gently undulating, rather dense network of predominantly shallow depressions microrelief : slightly irregular; gilgai, cowfoetoes and tussocks

- Vegetation type. The following vegetation types are distinguished only for soils in river basin land and in the area of major unit L3 of river levee land

code	description
b	bushland; shrubs less than 6 m high, covering up to 40% of the area
f	forest; woody vegetation more than 6 m high, mainly riparian forest along former river courses

4.4 Description of the soil mapping units

4.4.1 River levee land and crevasse splays

The soils of river levee land and crevasse splays (Chapter 2.2) consist in general of a complex of deep, usually stratified, and highly variable soils (Fig. 4.01).

The soils range in texture from sand to clay. On an average they are medium textured, although the lower part of the profile is more commonly a firm clay. Because of their relative high position in the area they are well drained to imperfectly drained.

The description of these soils is rather scanty. Only few observations have been made in the area of these soils due to the aim of the semi-detailed investigation: soils that were classified during the reconnaissance soil survey as unsuitable should be omitted. Therefore, only a more accurate delineation of these soils was carried out, but the area was not surveyed for extra information.

However, four physiographically recognizable units are distinguished. The most important unit (L1) consists of soils belonging to the meander-belt and its adjacent levees of the recent Tana River and its former courses (Mitapani and Lango la Simba). Related to this unit is unit L2: the soils of the crevasse splays. The deposits of this unit have a similar variable texture to those of the levee, though in many parts of this unit finer textured sediments of the former basin (backswamp) are found within 200 cm depth. The third unit (L3) consists of soils of the natural levee with predominantly fine textured material, but stratification with layers of fine sand occurs. In the area of this unit shallow former river courses or overflow channels are present. The vegetation pattern of the trees is presumably connected with the courses. On the fringes of the river basin land soils of unit L4 occur. They are homogeneous and consist of clay throughout.

Major unit L1

Soils of this major unit occur in and along the meander-belt of the Tana river and its former courses: the Lango la Simba and the Abarfarda river.

Extent : 3165 ha

Topography : flat to gently undulating, moderately high, in places high lying; in places very irregular due to the presence of abandoned river courses

Vegetation : grassland, bushed grassland, woodland and patches of riparian forests

Land use : open grazing

Drainage conditions : excessively to imperfectly drained, on an average well to moderately well drained; not flooded or shallow flooded for short periods; groundwater level mainly deeper than 200 cm (Sept. '81)

Soils:

general : brown to yellowish brown, often stratified, sand to clay; rich in micas. The texture of the topsoil ranges from, in places, sand to usually clay, the subsoil is frequently a firm clay

calcareousness : usually non-calcareous

soil reaction : pH-H_2O (1 : 2.5 v/v) ranges from 6.5-8.0 (few observations)

salinity : usually non-saline

sodicity : non-sodic

infiltration : no measurements have been carried out, but depending on the texture the infiltration ranges from rapid (sandy topsoil) to slow (topsoil with texture of clay)

hydraulic conductivity: variable from slow to rapid

Soil classification : eutric and vertic FLUVISOLS, partly saline phase

Land suitability for large-scale irrigated rice:

This major unit is classified as unsuitable (class NSu).
The different limitations are:

- the irregularity of the texture profile, which can cause great losses of irrigation water (seepage)
- the presence of abandoned river channels, causing a very irregular topography
- the remnants of riparian forest, indicating vegetation hindrance

Of the above mentioned limitations one, or a combination of two, or more is present in these areas.

Major unit L2

These are soils in the deposits of the breach through a natural levee (crevasse splays). The deposits occur as fans or tongues of sand elongated away from the river. The size of the crevasse splays differs from one place to another. An area of about 150 ha crevasse splay deposits occurs about 1 km south of the turn-off (track) to Hewani-Wema. This area is mistakenly indicated as Terrace land on the reconnaissance soil map.

Extent : 340 ha

Topography : slightly elevated levee, in places a gully (overflow channel) is still present

Vegetation : bushed grassland and bushed woodland; due to the presence of villages on these deposits, there are also areas without any vegetation or with some grasses only

Land use : habitation, open grazing

Drainage conditions : well drained to moderately well drained; usually no flooding; groundwater deeper than 200 cm

Soils:

general : complex of stratified sand and clay, rich in micas, over clay. Coarse textured sediments in gully

calcareousness : non-calcareous

soil reaction : the pH-H_2O(1 : 2.5 v/v) ranges from 6.0 in the topsoil to 7.5 in the subsoil

salinity : on the basis of a few observations it appears that soils are non-saline from 0-100 cm. At a depth of 70/80 cm slightly saline or moderately saline material is encountered, in places

sodicity : non-sodic

Soil classification : eutric and vertic FLUVISOLS, partly saline phase

Land suitability for large-scale irrigated rice:

Unsuitable: class NSu.
The stratification of sand and clay together with the elevated position of these soils are the most important limitations.

Major unit L3

Soils of this major unit occur on the natural levee of the Mitapani river course and the Abarfarda river course. Soils on the levee of the Mitapani river occur in the transition from the meander-belt area (mapping unit L1) to the basin land of the floodplain (mapping unit B...). The boundary between soils of major unit L1 and those of major unit L3 is rather vague in several places, particularly south of Galili.

These soils are predominantly fine textured with inclusions of layers with micaceous fine sand. Sinkholes up to 0,5 m deep and 0,5 m^2 in extent are usually present. Only a limited number of observations are made in the area of these soils.

Extent : 720 ha

Topography : flat to very gently undulating, in places irregular due to the presence of small and shallow overflow channels

Vegetation : bushed grassland, bushland (mainly Acacia sp.) and riparian forest

Land use : extensive open grazing

Drainage conditions : moderately well drained

Soils:

general : dark brown to brown, clay to clay loam, in places over stratified micaceous sand and clay. The presence of layers of sand is irregular

calcareousness : non-calcareous

soil reaction : pH-H_2O (1 : 2.5 v/v) varies from 6.5-8.0 (neutral to moderately alkaline)

salinity :
- soils that are non-saline to at least 100 cm have salinity profile S0
- soils that are non-saline, to at least 50 cm, over moderately saline, have salinity profile S2

sodicity : presumably non-sodic, in places sodic in subsoil

Soil classification : vertic FLUVISOLS, partly saline phase

Land suitability for large-scale irrigated rice:

soil mapping unit	limitations main	limitations minor	land suitability	extent (ha)
L3 II S0	texture	-	3Z	40
L3 II S0 f	texture/vegetation	-	NSu	210
L3 II S0 b	texture/vegetation	-	NSu	140
L3 II S2	texture/salinity	-	3zs	175
L3 II S2 b	texture/sal./vegetation	-	NSu	155

Major unit L4

The soils of this major unit occur on the transition of the levee land to the basin land.

Extent : 200 ha

Topography : flat

Vegetation : bushed grassland (mainly Acacia sp.)

Land use : open grazing

Drainage conditions : moderately well to imperfectly drained

Soils:

general : dark brown to brown clay, over grayish brown clay

structure : the topsoil has a weak to moderate, coarse prismatic structure, breaking into weak, fine subangular and angular blocks. The subsoil has mainly moderate, medium angular blocks; medium to thick slickensides occur

calcareousness : non-calcareous

soil reaction : pH-H_2O (1 : 2.5 v/v): 6.5-8.0 (neutral to moderately alkaline)

salinity : predominantly non-saline to at least 100 cm (salinity profile S0), but in places (30 ha) non-saline from 0-50/80 cm over moderately saline (salinity profile S2). Deeper than approx. 100 cm: usually moderately saline. Groundwater is strongly saline (EC more than 10 mS/cm)

sodicity : usually non-sodic from 0-100 cm. A higher level of measured sodicity may be due to incomplete leaching during sample treatment in the laboratory.

Soil classification : vertic FLUVISOLS, partly saline phase, partly saline-sodic phase

Land suitability for large-scale irrigated rice:

soil mapping unit	limitations main	limitations minor	land suitability	extent (ha)
L4 I S0	-	-	1	150
L4 II S0	-	topography	1(t)	20
L4 I S2	salinity	-	2s	30

Representative profile: profile description no. 1 (Appendix 1)

4.4.2 Soils of the river basin land

These soils are subdivided according to differences in sedimentation (Table 4.01). They consist mainly of heavy to very heavy clay to at least 80/100 cm depth.

The soil have a strong blocky or prismatic structure when dry. The blocky and/or prismatic structure is moderately weak when the soil is moist to wet. Very often, polished and grooved surfaces ("slickensides") are present on the structure elements (Fig. 4.02).

Wide and deep cracks develop in the dry season. This feature and the presence of slickensides indicate the "vertic" characteristics of these soils. Soils have a high content of 2:1 lattice clays and hence a high cation exchange capacity. Base saturation is high.

Usually the soils are non-calcareous. In places $CaCO_3$ concretions occur in non-calcareous material. The pH is generally between 6.5 and 8.0.

In general the soils are non-saline in the top 80/100 cm. With depth, salinity often increases to moderately saline. Groundwater is often strongly saline, particularly in deep basin clay soils. Salinity values of more than 20 mS/cm are no exception.

The soils are usually non-sodic, but sodic phases do occur. The exchangeable sodium increases with depth. This reflects the presence of saline groundwater and, in places, the presence of older alluvial deposits.

The physical characteristics of the river basin soils were measured in a moist condition of the soil. The basic infiltration ranges from 0.6 mm/hr in wet soils to more than 20 mm/hr in relatively dry soils. The median value is approximately 1.5 mm/hr. When saturated, these soils have a very slow infiltration rate.

The hydraulic conductivity, at 30-100 cm depth, ranges from 1 to 11 mm/day (median value of 7 mm/day). This slow hydraulic conductivity implies that it is very difficult to achieve proper drainage in these soils.

Deep basin soils (B)

These soils, up to a depth of two metres, consist of cracking ("vertic") clay of recent fluviatile origin. According to differences in drainage conditions three major soil units are distinguished. Each major unit is subdivided in several soil mapping units according to differences in relief, salinity, profile and vegetation type.

Major unit B1

These soils occur on the fringes of the levee land, mainly north of the Garsen-Witu road.

Extent : 1595 ha

Topography : flat, moderately high lying; weak gilgai

Vegetation : grassland and bushed grassland; predominantly Acacia sp. and/or palmtrees (doumpalms); North of the Garsen-Witu road locally woodland

Land use : extensive open grazing

Drainage conditions : moderately well to imperfectly drained; flooding less than 40 cm high; groundwater level usually deeper than 2 metres

Soils:

general : these deep soils have a 10-20 cm thick topsoil of very dark gray clay overlying dark brown clay

structure : the topsoil usually has a prismatic structure, breaking into fine angular and subangular blocky elements. Moderate, medium to coarse angular blocks are present in the subsoil to a depth of 100/150 cm. Usually slickensides are present

calcareousness : usually non-calcareous, in places $CaCO_3$ concretions occur in a non-calcareous subsoil

soil reaction : pH-H_2O (1 : 2.5 v/v) ranges from about 6.5-7.5 in the topsoil to 7.0-8.0 in the subsoil

salinity : predominantly non-saline from 0-40/50 cm. North of the Garsen-Witu road mostly non-saline up to 70/80 cm (salinity profile S0), in places however slightly to moderately saline at 70/80 cm and in a few places slightly saline throughout (salinity profile S2). These inclusions of deviating salinity profiles are indicated on the soil map. South of the Garsen-Witu road areas that are non-saline from 0-70/80 cm (salinity profile S0) alternate with areas that are non-saline from 0-40/50 cm and slightly to moderately saline at 70/80 cm (salinity profile S1 and S2). South of the Abarfarda river in some areas, a non-saline topsoil overlies a subsoil that is non-saline at 40/50 cm, but moderately saline at 70/80 cm (salinity profile S2). In other areas the subsoil is slightly to strongly saline at 40/50 cm and moderately to strongly saline onwards (salinity profile S3 and salinity profile S4)

sodicity : usually non-sodic; deeper than one metre exchangeable sodium percentages are as high as 30%. Part of this sodium occurs in the soil solution, the sum of exchangeable cations considerably exceeds the CEC. Incomplete leaching of the soil samples may be the reason

other chemical aspects : CEC-soil varies from 25-55 me/100 g approximately infiltration : very slow on moist to wet soils, moderately slow when soils are dry (<1cm/day)

hydraulic conductivity when wet : very slow

Soil classification : vertic FLUVISOLS, non-saline and saline phases

Land suitability for large-scale irrigated rice:

soil mapping unit	limitations main	limitations minor	land suitability	extent (ha)
B1 I So	-	-	1	585
B1 I So f	vegetation	-	3T	55
B1 I So/S1	-	-	1	185
B1 I S1	-	-	1	30
B1 I S2	salinity	-	2s	260
B1 I S3	salinity	-	3s	105
B1 II So	-	topography	1(t)	185
B1 II So b	-	topography	1(t)	130
B1 II S1	-	topography	1(t)	60
			total	1595

Representative profiles: profile descriptions nos. 2, 3, 4 and 5 (Appendix 1)

Major unit B2

These soils occur in areas adjacent to the central parts of the river basin land.

Extent : 2145 ha

Topography : flat to very gently undulating because of depressions and shallow gullies; moderately low lying; gilgai microrelief

Vegetation : grassland (grasses and, in places, sedges) or bushed grassland (Acacia sp.), in a few places doumpalms; north of the Garsen-Witu road in places woodland (fig. 4)

Land use : extensive open grazing and, in a few places, wildlife grazing

Drainage conditions : mainly imperfectly drained, locally poorly drained; flooding from 20/40 - 60/80 cm; groundwater level from 180 cm to deeper than two metres (Sept. '81)

Soils:

general : 10-20 cm thick topsoil of very dark gray clay, in places black humic clay, over dark grayish brown, cracking clay

structure : the topsoil has a weak to moderate, very fine to fine subangular blocky structure. To approximately 50 cm depth there is a coarse prismatic structure, breaking into fine to medium subangular blocky elements. From 50 to 100/150 cm depth medium to coarse blocky elements are present. Medium to thick slickensides are usually present

calcareousness : usually non-calcareous, in places $CaCO_3$ concretions in non-calcareous material

soil reaction : pH-H_2O (1 : 2.5 v/v) ranges from 6.0 to 7.0 in the topsoil and from 6.5 to 7.5 in the subsoil

salinity : The soils are non-saline to 40/50 cm depth except for a small area south of the Lango la Simba bridge on the Garsen-Witu road. Soils there are non-saline to 20/30 cm depth and strongly saline at 40/50 cm depth and onwards (salinity profile S4). North of the Garsen-Witu road non-saline clay extends to 70/80 cm depth (salinity profile S0), in places the clay is slightly to moderately saline at that depth (these inclusions are indicated on the soil map). South of the Abarfarda river course the bulk of the soils is non-saline at 20 and 40/50 cm depths and moderately saline at 70/80 cm depth and onwards (salinity profile S2)

sodicity : usually the soils are non-sodic when the clay in the top metre is non-saline. The amount of sodium increases considerably in soil layers that are slightly to moderately saline. When analysed as exchangeable sodium the ESP is high enough to characterize the soil as sodic phase (see profile descriptions ncs.7 and 8)

infiltration : very slow when wet; 2-9 mm/hr.

hydraulic conductivity when wet : very slow, 0,4-0,7 cm/day

Soil classification: vertic FLUVISOLS, partly saline phase

Land suitability for large-scale irrigated rice:

soil mapping unit	limitations main	limitations minor	suitability class	extent (ha)
B2 I S0	-	-	1	270
B2 I S1	-	-	1	105
B2 I S2	salinity	-	2s	125
B2 II S0	-	topography	1(t)	810
B2 II S0 f	vegetation	-	3T	85
B2 II S1	-	topography	1(t)	260
B2 II S2	salinity	topography	2s(t)	325
B2 II S4	salinity		NSs	50
B2 III S0	topography	-	2t	75
B2 III S2	salinity and topography		2st	40
			total	2145

Representative profiles: profile descriptions nos.6, 7, 8 and 9 (Appendix 1)

Major unit B3

Soils of this major unit occur in the central parts of the basins and in depressions.

Extent	: 3910 ha
Topography	: predominantly flat to very gently undulating mesorelief with a wide network of shallow depressions on gullies (relief classes I and II). A rather dense network of predominantly shallow depressions occurs in a relatively small area with a very gently undulating mesorelief (relief class III). Microrelief varies, usually uneven due to grasses and sedges on tussocks, cowfoetoes, elephant prints and gilgai
Vegetation	: grassland (grasses and sedges). North of the Garsen-Witu road locally woodland (indicated with additional feature f on the soil map)
Land use	: extensive open grazing and wildlife grazing
Drainage conditions	: poorly drained, in places very poorly drained; the height of the seasonal flood varies from 60/80 cm to more than 120 cm; groundwater >1.80 m (September 1981)

Soils:

general	: a 10–20 cm thick topsoil of very dark gray, in places black, humic to peaty clay overlies dark gray, cracking clay. The latter changes with depth into dark grayish brown, cracking clay (fig. 4.03)
structure	: the topsoil has a very fine to fine subangular blocky structure. The subsoil either has a complex structure, consisting of a prismatic macro-structure breaking into angular blocks or has an angular blocky structure throughout. Size of the blocks varies from fine to coarse. The coarse angular blocky structure usually occurs at greater depth and coincides with the presence of common to abundant slickensides. Usually slicken-sides start at a depth of 20 to 60 cm below the surface
calcareousness	: usually non-calcareous throughout; in places $CaCO_3$ concretions in a non-calcareous matrix
soil reaction	: pH-H_2O (1 : 2.5 v/v) varies from 6.0 to 7.0 in the topsoil and from 6.6 to 8.0 in the subsoil
salinity	: predominantly non-saline from 0 to 100 cm (salinity profile S0). In very few places non-saline from 0–40/50 cm depth and slightly saline onwards (salinity profile S1). Salinity of the subsoil deeper than 100 cm varies from non-saline to moderately saline
sodicity	: usually non-sodic in the top metre. The amount of sodium increases considerably in soil layers that are slightly to moderately saline. When analysed as exchangeable sodium the ESP is high enough to charac-terize the soil as sodic phase
infiltration	: these soils have a very slow to slow infiltration. The basic infil-tration rate varies from 0.3 to 5.6 mm/hr on 14 sites in relatively wet soils. The median value is 0.9 mm/hr (not adjusted for evaporation

losses during measurement). Sites on a soil with very narrow cracks because of drying, have basic infiltration rates of 7 and 11.9 mm/hr (soil profile description no. 19, Appendix 1)

hydraulic conductivity : very slow when wet, 1-11 mm/day (at 30-100 cm depth) for 17 sites on relatively wet soils

Soil classification : vertic FLUVISOLS

Land suitability for large-scale irrigated rice:

soil mapping unit	limitations main	minor	suitability class	extent (ha)
B3 I S0	-	-	1	785
B3 I S1	-	-	1	5
B3 II S0	-	topography	1(t)	2770
B3 II S0 f	vegetation	-	3T	100
B3 II S1	-	topography	1(t)	10
B3 III S0	topography	-	2t	245
			total	3915

Representative profiles: profile descriptions nos.12, 13, 14, 15, 16, 17, 18, 19, 20, 21 (Appendix 1)

Basin-over-levee soils $\frac{B}{L}$

These soils consist of cracking ("vertic") clay to a depth of at least one metre, over soil material of variable texture. The subsoil layers originate from sedimentation in the meander-belt of a former Tana River course.

Texture of the subsoil ranges from micaceous fine sand to sandy clay. The subsoil is in places calcareous and stratified.

The basin clay in the top metre does not differ from the clay in the top metre of the adjacent deep basin soils (major unit B). Subdivision of these soils according to drainage conditions, topography, salinity and vegetation is carried out as for deep basin soils. A large similarity exists but for the subsoil and the presence of hardly visible silted up former river courses.

Two major units are distinguished.

Major unit $\frac{B2}{L}$

These soils occur in a small area north of the Garsen-Witu road and in an area south of it. An elongated area with these soils extends in the eastern part of the project area, from the Lango la Simba near Galili to the Abarfarda near Moa.

Extent : 929 ha

Topography : flat to very gently undulating mesorelief with a wide network of shallow depressions and gullies (relief classes I and II). Some of the depressions are the remnants of former river courses that have been silted up. Microrelief is smooth except for gilgai,small (sedge-) tussocks and cowfoetoes

Vegetation : grassland (grasses and, in places, sedges (Fig. 4.04) or bushed grassland (Acacia sp.). A small area with a clearly visible former river course is woodland

Land use : extensive open grazing and wildlife grazing

Drainage conditions : mainly imperfectly drained, in places poorly drained; the height of the seasonal flood is 20/40-60/80 cm; groundwater >150 (Sept. 1981)

Soils:

general : 10-20 cm very dark gray, in places black, humic clay over dark grayish brown, cracking clay. Deeper than 100 cm the basin clay changes into micaceous, usually stratified soil material with a texture of sand to clay structure : the topsoil has a moderate, very fine subangular blocky structure, changing into a coarse prismatic structure which breaks into moderate fine to very fine angular blocks. From 50/70 cm depth structure consists of weak to medium, coarse, angular blocks. Slickensides are usually present. The "levee" subsoil material has a little or no structure

calcareousness : usually non-calcareous, in places $CaCO_3$ concretions in non-calcareous matrix

soil reaction : pH-H_2O (1 : 2.5 v/v) ranges from 6.5-7.5 in the topsoil and from 7.5-8.5 in the subsoil

salinity : non-saline throughout (salinity profile SO)

sodicity : presumably non-sodic, though, with depth slightly increasing salinity coincides with an increase in sodium amount

infiltration : slow to very slow when wet,(on two sites in a soil which had started drying out infiltration rates were 14.1 and 13.2 mm/hr due to cracks

hydraulic conductivity very slow (7 mm/hr for period 3-5 hrs after start of measurement in soil layer 30-100 cm depth)

Soil classification : vertic FLUVISOLS

Land suitability for large-scale irrigated rice:

soil mapping unit	limitations main	minor	suitability class	extent (ha)
$\frac{B2}{L}$ I SO	-	texture (subsoil)	1(z)	80
$\frac{B2}{L}$ II SO	-	texture (subsoil) and topography	1(t.z)	830
$\frac{B2}{L}$ II SO f	vegetation	texture (subsoil) and topography	NST	20
			total	930

Representative profile: profile description no. 10 (Appendix 1)

Major unit $\frac{B3}{L}$

Soils of this major unit occur in the relatively lowest parts of a silted up meander-belt area of a former river course. More than 1 m basin clay overlies micaceous, stratified "levee" material with a texture of sand to clay. These soils are largely similar to major unit B3 of the deep basin soils.

Extent	: 80 ha
Topography	: flat to very gently undulating mesorelief, remnants of former river course are present; microrelief is uneven due to (sedge-) tussocks, cowfoetoes, elephant prints and gilgai
Vegetation	: grassland, mainly sedges
Land use	: extensive open grazing
Drainage conditions	: poorly drained; the height of the seasonal flood is 60/80 cm to more than 1.20 m

Soils:

general	: 10-20 cm very dark gray, in places black, humic to, in places, peaty clay over dark gray to grayish brown, cracking clay. Deeper than 100 cm the texture of the soil changes into micaceous, usually stratified sand to clay
structure	: similar to major unit B3 except for the "levee" subsoil which has angular blocky structure when texture is clay but is single grain when sand prevails
calcareousness	: usually non-calcareous, in places slightly calcareous in subsoil
soil reaction	: pH-H_2O (1: 2.5 v/v) varies from 6.5-7.5 in the topsoil to 7.0-8.0 in the subsoil
salinity	: non-saline throughout in the top metre
sodicity	: presumably non-sodic

Soil classification : vertic FLUVISOLS

Land suitability for large-scale irrigated rice:

soil mapping unit	limitations main	limitations minor	suitability class	extent (ha)
$\frac{B3}{L}$ II SO	-	texture (subsoil)	1(z)	80

Representative profiles: nil

Basin-over-terrace soils $\frac{B}{T}$

Soils of this unit have at least 80/100 cm cracking ("vertic") clay over clay or, in places, loam to coarse loamy sand of old alluvial origin. The cracking clay is a basin clay comparable to that of the deep basin soils. The old alluvial sediments usually have an alkaline to strongly alkaline soil reaction. Coarse $CaCO_3$-concretions are a common feature in these sediments (Fig. 4.05). The degree of dispersion of the analyzed soil samples was high. The exchangeable sodium percentage (ESP) is presumably 10 or more. Soil material from 0-100 cm depth is usually non-saline or slightly saline from 70-300 cm.

Three major units are distinguished according to differences in drainage conditions/relative height. They occur on the fringes of the Terrace land.

Major unit $\frac{B1}{T}$

Extent : 55 ha

Topography : flat mesorelief and smooth microrelief except for moderate gilgai

Vegetation : bushed grassland

Land use : extensive open grazing

Drainage conditions : moderately well drained

Soils:

general : 10-20 cm very dark gray clay over dark brown, cracking clay, deeper than 80/100 cm changing into dark gray clay, in places into loam to coarse loamy sand (old alluvial sediments)

calcareousness : predominantly non-calcareous throughout, deeper than 100 cm $CaCO_3$ concretions

soil reaction : pH-H_2O (1 : 2.5 v/v) varies from 6.5-8.0 in the topsoil and increases to 8.0/8.5 or more in the subsoil

salinity : non-saline throughout

sodicity : usually non-sodic, in places sodic in the top metre and deeper than 80/100 cm sodic

infiltration/ hydraulic conductivity : not measured but probably slow, very slow when wet

Soil classification : vertic FLUVISOLS, partly saline phase, partly sodic phase

Land suitability for large-scale irrigated rice:

Soil mapping unit	limitations main	limitations minor	suitability class	extent (ha)
$\frac{B1}{T}$ I S0	-	subsoil	1(d)	30
$\frac{B1}{T}$ I S1	-	subsoil	1(d)	25
			total	55

Representative profiles: nil

Major unit $\frac{B2}{T}$

Extent : 285 ha

Topography : flat to very gently undulating mesorelief with a wide network of shallow depressions; microrelief is smooth except for gilgai, grass- and sedge tussocks and cowfoetoes

Vegetation : grassland (grasses and in places sedges)

Land use : extensive open grazing and wildlife grazing

Drainage conditions : imperfectly drained, in places poorly drained

Soils:

general : 10-20 cm very dark gray, in places black, humic clay over dark grayish brown, cracking clay. Deeper than 80/100 cm the soil material changes into dark gray clay, in places into clay loam to coarse loamy sand (old alluvial deposits)

structure : the topsoil has a very fine angular and subangular blocky structure. From 25 cm to 70/90 cm depth a coarse prismatic structure, breaking into coarse, angular blocks, is present. Deeper than 70/90 cm coarse, angular blocks coincide with abundant slickensides

calcareousness : usually non-calcareous, in the top metre, deeper than one metre calcareous with coarse $CaCO_3$ concretions

soil reaction : pH-H_2O (1 : 2.5 v/v) varies from 7.0-8.0 in the top metre and increases usually to more than 8.5 in the deeper subsoil

salinity : non-saline throughout or slightly saline from one metre onwards

sodicity : usually non-sodic in the topsoil, but sodic in the subsoil

infiltration/ hydraulic conductivity : very slow to slow infiltration when wet, hydraulic conductivity slow when wet

Soil classification : vertic FLUVISOLS, partly sodic phase

Land suitability for large-scale irrigated rice:

soil mapping unit	limitations main	limitations minor	suitability class	extent (ha)
$\frac{B2}{T}$ I SO	-	sodicity (subsoil)	1(d)	185
$\frac{B2}{T}$ II SO	-	sodicity (subsoil) topography	1(t,d)	100
			total	285

<u>Representative profile</u>: profile description no. 11 (Appendix 1)

<u>Remarks</u> : inclusions of soils with a subsoil consisting of probably transported old alluvial deposits (e.g. micaceous subsoil of representative profile)

Major unit $\frac{B3}{T}$

Soils of this major unit occur in an area south of the large Terrace land remnant in the floodplain

Extent : 120 ha

Topography : flat mesorelief; smooth microrelief with weak gilgai and few sedge tussocks

Vegetation : grassland, predominantly sedges

Land use : extensive open grazing

Drainage conditions : poorly drained

Soils:

general : 10–20 cm very dark gray, in places black, humic to peaty clay over dark gray, cracking clay. Deeper than 80/100 cm dark gray clay with $CaCO_3$ concretions or, in places, clay loam to coarse loamy sand (old alluvial deposits)

structure : not observed but probably similar to B3

calcareousness : non-calcareous in the top metre, the old alluvial deposits are calcareous with coarse $CaCO_3$ concretions

soil reaction : pH-H_2O (1 : 2.5 v/v) varies from 7.0 to 8.0 in the top metre and increases in the subsoil to values of more than 8.5

salinity : non-saline throughout

sodicity : usually non-sodic, in places sodic and deeper than 80/100 cm sodic

infiltration/ hydraulic conductivity : very slow to slow when wet

Soil classification : vertic FLUVIOSOLS, partly sodic phase

Land suitability for large-scale irrigated rice:

soil mapping unit	limitations main	limitations minor	land suitability class	extent (ha)
$\frac{B3}{T}$ I SO	-	subsoil	1(d)	120

Representative profile: nil

Basin soils association $(B1/\frac{L}{B})$

This association consists of two soil units and comprises an area of 140 ha in the southern part of the surveyed area. The complex pattern may be related to a former system of overflow channels from the Abarfarda in southern direction which are silted up afterwards, mainly with heavy clay.
One unit is similar to the B1 unit of the deep basin soils. Soils of this component usually occur in between shallow gullies with an irregular pattern and cover the largest part of this unit. Vegetation consists of bushes (mainly acacia spec.) and grasses (bushed grassland) and the land is hardly used for grazing. The topmetre is usually non-saline but encountered groundwater is strongly saline. For more detailed information reference is made to the description of major unit B1. One difference is that the dark brown clay changes into dark gray cracking clay within 100 cm depth.
Soils of the second component $\frac{(L)}{B}$ usually occur in the gullies.

Major unit $\frac{B1/L}{B}$

Extent : 140 ha

Topography : flat to very gently undulating mesorelief with a complex network of shallow gullies and depressions

Vegetation : bushed grassland (B1) and grassland (grasses and reeds; $\frac{L}{B}$)

Land use : very extensive open grazing and wild life grazing

Darinage conditions : moderately well to imperfectly drained

Soils : (see description B1 of deep basin soils for component B1)

Component $\frac{L}{B}$

general : 20-30 cm dark gray over complex of sand to clay. This complex is often stratified, rich in micas and changes into gray cracking clay within 200 cm depth

calcareousness : non-calcareous

soil reaction : pH-H_2O (1 : 2.5 v/v) varies from 6.5 to 8.0

salinity : non-saline in the top metre

sodicity : presumably non-sodic

Soil classification: vertic FLUVISOLS

Land suitability for large-scale irrigated rice:
This association of basin soils is appraised with suitability class 3 p.z due to the variability at short distance and the presence of a layer of fine sand in one of the components.

4.4.3 Soils of the Terrace land

The soils of the Terrace land are developed on old alluvial sediments. They occur adjacent to the floodplain proper and in the floodplain in non-flooded, high lying inliers (erosion remnants, see also Fig. 2.03).

Three major soil units are distinguished.

The soils of unit TO1 are left undifferentiated, being of no interest for the project area because of their occurrence on a markedly higher level than the floodplain. In short, they consist of coarse to fine textured, often saline and sodic soil material. Few observations are carried out in this unit. Soils in the transition zone from the floodplain to the higher lying Terrace land, west and north-west of Moa, are grouped in unit TO2.
In some places a thin cover of recent fluvial sediments is present. In general these soils consist 20-70 cm dark gray, cracking clay over slaking gray clay. The subsoil material is usually strongly alkaline (pH-H_2O often 8.5 or more) and sodic.

The third unit, TOb, comprises soils in a low lying area south of Moa. They consist of 60-70 cm black, cracking ("vertic") clay over very dark gray, cracking clay. These soils have a neutral to moderately alkaline soil reaction and are non-sodic, non-saline and non-calcareous.

Major unit TO1

Extent : 1200 ha

Topography : flat to very gently undulating

Vegetation : woodland alternating with (bushed) grassland, and bushland

Land use : very extensive open grazing, mainly wildlife grazing

Drainage conditions : moderately well to poorly drained

Soils : coarse to fine textured, undifferentiated

Soil classification : orthic and vertic SOLONETZ and pellic VERTISOLS

Land suitability for large-scale irrigated rice:

Suitability class NS: unsuitable

Major unit T02

Extent : 680 ha

Topography : flat to very gently undulating

Vegetation : grassland, in places bushed grassland (Acacia sp.)

Land use : extensive open grazing

Drainage conditions : imperfectly drained, in places poorly drained

Soils:

general : 20–70 cm dark gray, in places black, cracking clay over slaking, gray clay. In places 20–80 cm dark grayish brown clay (recent fluvial sediments) over slaking, gray clay (old alluvial deposits)

calcareousness : non-calcareous, deeper than 50–70 cm calcareous and many fine to coarse $CaCO_3$ concretions

soil reaction : the dark gray clay in the top metre is usually moderately alkaline. The gray clay has a higher pH-H_2O value, often values of more than 8.5 are found (strongly alkaline)

salinity : from 0-50/70 cm the soils are non-saline to slightly saline, deeper they are usually moderately saline, in places slightly saline

sodicity : starting at variable depths, but at least within one metre from the surface sodic material is present. The degree of sodicity, based upon the high degree of dispersion of soil samples, is high

infiltration/ hydraulic conductivity : no measurements are carried out on these soils. Very slow to slow when wet may be presumed

Soil classification : vertic SOLONETZ, pellic VERTISOLS, sodic phase

Land suitability for large-scale irrigated rice:

Suitability class 3 due to the presence of easily dispersing soil material (old alluvial deposits), starting at 20–70 cm below the surface. Because of the low structure stability of this soil material occurring at shallow depths, difficulties may be expected in construction of canals and drains.

Major unit T0b

Extent : 105 ha

Topography : flat and smooth except for gilgai and cowfoetoes

Vegetation : grassland

Land use : open grazing

Drainage conditions : poorly to very poorly drained

Soils:

general	: 60–70 cm black, cracking clay over very dark gray, cracking clay
calcareousness	: non-calcareous throughout
soil reaction	: neutral to moderately alkaline
salinity	: non-saline
infiltration/ hydraulic conductivity	: very slow when wet

Soil classification : pellic VERTISOLS

Land suitability for large-scale irrigated rice:

Class 1: highly suitable, no major limitations regarding soil and land qualities

4.5 Subsoil investigations

Information about the subsoil was collected from 40 augerings to a depth of five metres below the surface. Augerings from the bottom of the soil profile pit are included. At several places soil conditions prevented augering to five metres depth, for instance sand flowing into the auger hole.

The data from the subsoil material include texture, pH-H_2O and electrical conductivity (EC mS/cm) of (1:2.5 v/v) soil samples and pH-H_2O and EC of the groundwater.

Some general conclusions are summarized below:

Texture

The subsoil of the deep basin soils in river basin land (Chapter 4.4.2) consists mainly of clay or sandy clay. The sandy clay contains very little, very fine micaceous sand. At several places however micaceous, very fine sand occurs deeper than two metres. Particularly the large area of deep basin soils south of the Garsen-Witu road (unit B3) comprises soils with sand in the deep subsoil. The sand may be attributed to a silted over, former meander-belt.

Augering to five metres depth was impossible in the basin-over-levee soils, due to sand flowing into the auger hole with the groundwater. In the vicinity of the former river courses sand, or stratified sand and clay, was always found. Near Moa, subsoil material of old alluvial origin was encouterned.

Soil reaction

The pH-H_2O values of deep subsoil samples are no different from those of the samples from less than two metres depth, except when old alluvial sediments were encountered. In general, the pH-H_2O pattern with depth as shown in Figure 4.06 can be applied to most soils: a rather constant pH-H_2O (neutral to moderately alkaline) with depth.

Salinity

The degree of salinity of the subsoil and the groundwater is closely related to the texture of the subsoil. A soil consisting of heavy clay throughout often has a moderately saline subsoil. Corresponding salinity of groundwater reaches EC values of 20 mS/cm or more. In general, groundwater in these soils has

EC values between 10 and 20, the values of the EC in (1:2.5 v/v) soil samples varies from 2 to 8 (slightly saline to moderately saline). The ratio of the EC value of the groundwater and the EC (1:2.5 v/v) value of a wet soil sample varies from 3 to 5, roughly estimated at 4.

Due to the very slow hydraulic conductivity of these heavy clay soils, refreshment of the groundwater with non-saline floodwater is of minor importance. Accumulation of salts from the floodwater probably occurs in these soils.

Salinity is less severe if "levee" material is present (varying from micaceous, very fine sand to slightly stratified sandy clay). EC values are less than 2, both of soil samples and groundwater. Refreshment of the groundwater will occur by infiltrated floodwater.

The EC (1:2.5 v/v) of moist soils has a relative maximum in soil horizons between 100 and 180 cm below surface. During the soil survey nests of fine salt crystals are frequently observed at that depth.

The EC-data of the salinity at depths 110 and 160 cm below the surface and those of the groundwater are indicated on a map (Appendix to the report). The data reveal that the soil deeper than one metre is, often, slightly to moderately saline. Also deep basin soils with a non-saline top metre (salinity profile SO) have this salinity pattern. The EC data of the groundwater under estimate the salinity hazard because auger holes in deep clay soils hardly produced any groundwater during the soil survey. Groundwater was often encountered in soils with a lateral movement of water because of the presence of "levee" material. The groundwater salinity is less severe in these soils.

4.6 Soil chemical characteristics and soil fertility

4.6.1 Soil reaction (pH), calcium carbonate and gypsum

Soil reaction (pH), which is expressed by the negative logarithm of the hydrogen activity in a soil/water suspension or extract, is determined in the field laboratory on soil samples (see Chapter 3.3).

The bulk of the soils in the survey area have pH-values ranging from 6.5 to 8.5. The pH-values in the topsoils are predominantly in the range of 6.5 to 7.5. These values indicate that the topsoil is "neutral" and without alkaline earth carbonates. Usually, the pH-values increase with depth to values between 7.5 and 8.5. pH-values of 8.5 or more usually occur in (sub)-soils where presumably alkaline earth carbonates are present and where the soil is more or less sodic.

Fig. 4.06 gives the changes in electrical conductivity (EC) and soil reaction (pH-H_2O) with depth for six representative profile pits. In almost all soils the pH of the subsoil is rather constant with depth and is not correlated to the electrical conductivity.

The presence of calcium carbonate and other carbonates was quantitatively estimated by the effervescence with hydrochloric acid (HCl) on the soil material from the auger hole in the field. Usually, the soils in the river basin land and river levee land are non-calcareous in the top 100 cm.

Gypsum was roughly estimated in the field by visual observation of the amount of gypsum crystals, if distinguishable. Gypsum crystals are not observed in the top metre of the soil. When present, they occur predominantly in small amounts at depths ranging from 110/140 to 150/180 cm below the surface. The occurrence of gypsum crystals coincides with other crystals/salts in nests and small lenses at this depth. Therefore, crystals can be mistaken for gypsum crystals. The NAL data for $CaSO_4$ content indicate that the $CaSO_4$ content is usually less than 0,1 me/100 gram, so almost absent.

4.6.2 Salinity

The electrical conductivity of all samples from augerings and profile pits was measured in a field laboratory in suspension with a volume ratio of 1:2.5 (soil: water). See also Chapter 3.3. To estimate the weight ratio of these soil-water (1:2.5 v/v) suspensions first the moisture percentage of non-suspended soil samples was determined. Because of the limited equipment the moisture percentage is rather roughly estimated. Four representative soil samples with a texture of (heavy) clay showed on average of 23 (range 18-34) for the moisture percentage. The volume percentage water in these samples was estimated at 40%. The corresponding average water content of the 1:2.5 v/v samples was 195% out of the range 177-233. An average ratio of 1:2 (weight/weight) was established.

A saturated paste was prepared from identical material. The average saturation percentage of four pastes was 103% (range 87-121%). Assuming a linear inversed relation between the electrical conductivity and the water content of a sample, the ratio for the electrical conductivity of the saturation extract (ECe) and the one of the 1:2.5 v/v suspension is 2:1. This conversion factor 2 is applied for the appraisal of the salinity hazard for which the field laboratory data of approximately 4000 electrical conductivity measurements in 1:2.5 v/v samples are used. At NAL the electrical conductivity of all samples from profile pits was routinely measured in a 1:2.5 (vol./vol.) suspension that corresponds approximately with a weight/weight ratio of 1:2 (soil:water). Additionally, NAL measured the ECe of all those samples of which the EC 1:2.5 had exceeded 0.8 mS/cm.

The Ece and EC (1:2.5 v/v) were used for the definition of salinity classes (see Chapter 4.3.2). A saline phase is distinguished for soil classification purposes (FAO/Unesco, 1974) if some horizons within 100 cm of the surface have an electrical conductivity of the saturation extract higher than 4 mS/cm at 25°C. The corresponding value for the 1:2.5 v/v samples is 2 mS/cm.

Soils with a saline phase are differentiated according to the degree of salinity. The degree of salinity is expressed by means of a "salinity profile" for the soils in the survey area. The grouping of the salinity classes, which are established at 20, 40/50 and 70/80 cm depths, into a coded salinity profile is given in Chapter 4.3.2.

This subdivision connects with the criteria for salinity in the land evaluation. Identical salinity profiles are grouped, delineated on the soil map and coded as an additional feature (code SO, S1, S2, S3 and S4) to the major unit. Deviating salinity profiles within a coded area are indicated with a symbol (see legend).

The majority of the soils in the surveyed area are non-saline within 100 cm depth. Particularly major unit B3 in the low lying basin land shows this salinity pattern. However, Fig. 4.06 shows that deeper than 100 cm a saline subsoil occurs. The data on the salinity map (samples at 110 and 160 cm depths) support the idea that flooding only refreshes the first metre of this soil type. A moderately saline subsoil, starting within 70/80 cm depth, is present in parts of major unit B2.

Soils that are moderately to strongly affected by salinity at shallow depths occur in the river basin land in the vicinity of the river levees of the Lango la Simba.

4.6.3 Sodicity

Sodicity of a soil is described by the exchangeable sodium percentage (ESP) on the soil's exchange complex. Soils which have more than 6% saturation with exchangeable sodium in some horizons within 100 cm of the surface are marked as soils with a sodic phase (FAO-Unesco, 1974).

Based on the available laboratory data of soil samples analysed at NAL and partly supported by the degree of dispersion observed in the samples analysed in the field laboratory a sodic phase is indicated for some of the major soil units. It is stressed here that the sodicity of soils, as mentioned in the legend and in the description of the mapping units, should be considered as a rough indication.

A reliable differentiation needs laboratory determinations of the ESP-values of many more soil samples. To compensate for the lack of sufficient data of analysed samples, the degree of dispersion, the pH and EC (1:2.5 v/v) measured in the samples of augerings were taken into considerationas a provisional indication for the sodicity. Usually, ESP-values of more than 10 may be expected in non-saline soils or soil horizons which have a pH value of, roughly, more than 8.5. A high degree of dispersion supports the expectation. It is realised that this method is not fully reliable, but is was the best that could be done under the circumstances to trace sodic soil material.

The deep basin soils and the basin-over-levee soils in river basin land are characterized as usually non-sodic. The laboratory data of the described profiles indicate that, within a depth of 1 m, the exchangeable sodium percentage in several places increases to more than 6. However, the pH is often not high (8) and the calculated ESP may not be correct. Part of the analysed Na is probably not exchangeable Na of the exchange complex (see 4.6.4) but Na of the presumably not completely leached soil solution. Moreover the degree of dispersion of this soil material was not different from that of non-sodic material. Therefore, these soils are probably usually non-sodic, though within a depth of 1 m, the amount of Na may increase considerably because of a saline soil solution.

Soil material from horizons with a high pH, a typical bluish gray colour and coarse $CaCO_3$ concretions often disperse to a considerable extent. This is material from the old alluvial sediments; a characterisation which is supported by the physiographic occurrence.

Old alluvial sediments (sodic material) is present in basin-over-terrace soils, usually deeper than 80/100 cm. This highly dispersing material with a high pH occurs in the soils of the unit TO2 of Terrace land from 20/70 cm depth and onwards.

4.6.4 Cation exchange capacity and exchangeable bases

The cation exchange capacity (CEC) of the soils in the river basin land is rather high due to the high content of clay. It varies from 30 me per 100 gram soil with a texture of approximately 40% clay to 55 me per 100 gram soil with a texture of approximately 70% clay. On average the CEC per gram clay is 0.7-0.8 me. The CEC of topsoils is slightly higher because organic matter also contributes to the exchange complex.

The base saturation is the degree to which the exchangeable bases saturate the exchange comples of the soil. The major exchangeable bases are Ca, Mg, K and Na. The base saturation of the soils of the river basin land is at least more than 50%. Slightly to strongly saline soil horizons commonly have a base saturation of 100%. In these horizons the sum of exchangeable cations analysed in the laboratory exceed the CEC. This is an indication that the soil samples were not adequately leached before determination of the exchangeable bases. Base saturation in non-saline soil horizons varies considerably though some pattern is present. The topsoil is saturated for 50 to 80%, the higher values usually occurring in soils that are neutral to moderately alkaline. Below the topsoil the base saturation increases in general to values between 70 and 100%. Soils with a high CEC and a high base saturation are potentially fertile soils as they may provide adequately supply of plant nutrients. The major exchangeable bases are Ca, Mg, K and Na. The important nutrient K is always present in relatively low amounts, often not exceeding 1 me/100 gram soil. Another unfavourable condition is the relatively high amount of Na on the exchange complex which is associated with a considerable dispersion of the soil. This characteristic sodicity is dealt with in Chapter 4.6.3.

4.6.5 Soil fertility

Around most profile pits composite samples of the 0-20 cm topsoil were taken and subjected to a "Mass analysis" method for soil fertility evaluation. The results are presented in appendix 1. Some conclusions are given here.

Soil reaction is slightly acid. The organic matter content, which ranges from 1.0 to 2.6% org. C, is moderate to sufficient. Deeper than 20 cm the organic matter content decreases considerably rapidly to values of 0.2-0.4% org. C. The content of N is closely related to the organic matter content; the ratio between the org. C% and the N% varies from 5 to 8. The average content of N is moderate. The figures for available phosphorus (P) indicate a sufficient level. The average level is 32 ppm P (extreme values are not taken into account), the critical level below which P may be deficient is 20 ppm.

The available Ca varies roughly between 15 and 20 (me/100g) and available Mg between 7.5 and 9.5 (me/100 gr). The values can be considered as high to very high as the critical level is 2.0 for Ca and 1.0 for Mg.

Potassium figures indicate in general a level that can be considered as sufficient. Three composite samples have K-values below the critical level of 0.2-0.4 me/100 gram. Sodium content (in me/100 gram) is sufficiently below the critical level of 2.

4.7 Soil physical characteristics

4.7.1 Introduction

The physical characteristics of the soil which determine to a large extent the water retention and transmitting properties, the workability and structure stability are of importance for assessing the irrigation suitability. Chemical characteristics, particularly sodicity and its interaction with salinity, influence and possibly determine the physical characteristics of the soil.

4.7.2 Infiltration

Infiltration is the entry of water into the topsoil. Measurements of the infiltration rate were carried out in the field in the proximity of the profile pits.

The conditions for the infiltration measurements were in general those of a "wet run" infiltration. The moisture content of the topsoil was very close to the saturation percentage. At some locations, particularly in the relatively high basin areas, the topsoil was already starting to dry out and a few shallow and narrow cracks had developed. Infiltration is influenced largely by the moisture content. Dry soils are soils with cracks that facilitate the entry of water, resulting in a high and often variable infiltration rate. Even a wet run measurement on these initially dry soils results in relatively high values. Clay soils that have been inundated for a long period are swollen and the cracks have disappeared. Infiltration in these soils is slow as long as the soils are wet from the surface.

The double ring method was applied in duplo on most of the locations (Fig. 4.07). The inner rings had diametres of 20 and 30 cm, the accessory outer rings measured 32 and 53 cm. The rings were driven carefully to a depth of 15-20 cm into the soil at each site. The rings were filled up to about 10 cm with water. Refilling took place when the water level had dropped by about 5 cm. The water level was recorded after 1, 2, 3, 4, 5, 10, 20, 30, 40, 50, 60, 75, 90, 105, 120, 135, 150, 165, 180, 210, 240 and 300 minutes.

The infiltration rate was calculated for each double ring infiltrometer, using the formula

$$I\ cum = cT^m.$$

In which:
I cum = accumulated intake (cm)
T = elapsed time for each accumulated intake (hr)
c, m = constants ;
c and m were calculated, using double logarithmic paper.

The final or basic infiltration rate (I-bas) is a relatively constant rate which occurs after several hours. "Relatively constant" means that I-bas is achieved when the change per hour is less than 10%. The time (in hrs) for the calculation of I-bas is given by the formula $T = 10\ (1 - m)$ hrs. I-bas values range from 0.6 mm/hr on wet soils to more than 20 mm/hr on relatively dry soils with cracks that had started to develop. The very low value of 0.6 mm/hr roughly equals the order of the evaporation during the measurement. All data of measurements are collected in one group, as representative of river basin soils.

Table 4.02 gives a division according to the value of I-bas.

Table 4.02 Basic infiltration rates (mm/hr) in moist to wet river basin soils

	basic infiltration rate (mm/hr)					
range	0-1	1-2.5	2.5-5	5-10	10-20	>20
number	8	10	3	2	3	3

The median of the values is approximately 1.5 mm/hr. This indicates a low infiltration rate. The basic infiltration rate and the constants c and m are given in Table 4.03. They are grouped according to the drainage condition of the sites and in the sequence from high to low values.

The majority of the infiltration rates must be classified as low. Particularly the soils of the poorly drained basin soils (unit B3) have low values. They approach the evaporation, which was not determined and thus not substracted from the measured intake. Entry of water did not continue after some time in these almost saturated soils. The infiltration rates on observation sites P21 and P19 of major unit B2 are high (class moderately rapid and rapid). These sites were relatively dry and cracks were present. They confirm the previously made statement that:

1. infiltration in these clay soils depends largely on the moisture condition (and related presence of cracks) of the soil;
2. after long saturation infiltration drops almost to zero.

Table 4.03 The base infiltration rate and formula-constants c and m for 29 sites in river basin land

Soil mapping unit			c		m		Observation no.	Profile description no.
	site 1	site 2	site 1	site 2	site 1	site 2		
B1 I SO	1.3	2.6	1.34	1.2	0.21	0.28	P5	4
B2 II SO	37.5	26.6	0.86	0.52	0.61	0.63	P21	9
B2 II SO	14.1	13.2	0.53	0.42	0.55	0.57	P19	10
L								
B2 II SO	9.2	-	0.76	-	0.46	-	P4	7
B2 I SO	2.3	-	0.35	-	0.50	-	P7	6
B2 I S2	2.3	1.1	0.23	0.08	0.44	0.47	P11	5
B2 II SO	0.5	1.3	0.62	0.60	0.19	0.28	P17	11
T								
B3 II SO	11.9	7.0	0.32	0.76	0.59	0.43	P10	19
B3 I SO	4.2	-	0.80	-	0.37	-	P13	12
B3 I SO	5.6	0.9	0.011	0.011	0.96	0.69	P20	15
B3 II SO	2.5	1.1	0.054	0.013	0.62	0.69	P6	17
B3 II SO	1.6	1.6	0.027	0.004	0.65	0.92	P9	8
B3 I SO	0.8	-	0.10	-	0.41	-	P14	13
B3 I SO	1.8	0.3	0.013	0.058	0.76	0.36	P16	14
B3 II SO	0.4	0.7	0.13	0.072	0.32	0.44	P18	21
B3 II SO	0.6	0.7	0.001	0.006	1	0.73	P12	20

4.7.3 Hydraulic conductivity

The permeability of the subsoil was measured with the auger hole pour-in method at the profile pit sites (inversed auger hole method). Two auger holes of approximately 1 metre depth were filled with water to a depth of about 30 cm and the drop in the water level with time was recorded (Fig. 4.08). Hydraulic conductivity (k) was calculated with the equation given by ILRI (1974, Vol. III, p. 292). The results are presented in Table 4.04. K-values are given for two periods, 2-5 hours and 3-5 hours after start. Start is the moment that water is poured into the auger holes. These two periods are relevant for the calculation with the equation. The data from the 0-2 hrs period after start do not fit the straight line which is required for the use of the equation.

The very slow hydraulic conductivities imply that internal drainage is very difficult to achieve.

At the site of profile pit P12 the dropping of the water in the auger hole was recorded over a period of two days. Calculation of k for different periods resulted in a remarkably constant, but low value of 6 mm/day.

Table 4.04 Hydraulic conductivity values according to the inversed auger hole method

Soil mapping unit	Observation nr.	Hydraulic conductivity (mm/day) 2-5 hrs after start average of 2 sites	3-5 hrs after start average of 2 sites
B1 I SO	P5	10*	7*
B1 I S2	P11	10	9
$\frac{B2}{T}$ II SO	P17	10	0
B2 II SO	P21	10*	7*
$\frac{B2}{L}$ II SO	P19	8	7
B II SO	P4	16*	4*
B2 I SO	P7	7*	4*
B3 I SO	P20	15	11
B3 II SO	P10	11^5	10
B3 II SO	P2	11	8
B3 II SO	P9	7	8
B3 II SO	P10	9	6
B3 II SO	P6	3	3
B3 I SO	P14	2*	2*
B3 II SO	P18	2	1
B3 I SO	P16	1	1

The range of all hydraulic conductivity values for the 3-5 hrs period is 1-11 mm/day, with a median of 7 mm/day. The data of the 2-5 hrs period range between 1 and 16 mm/day with a median of 9 mm/day
* Value of one site

4.7.4 Subsurface infiltration

The percolation of water through a subsurface layer was measured with the so-called column method (Bouma, J., 1979) at three sites where profile pits were dug. A column with a diameter of 30 cm and height of 30 cm was made in a 60 cm deep profile pit.

The laborious preparation was necessary to achieve a non-disturbed soil column which is connected with the subsoil at 60 cm depth. The column is coated with plaster of Paris to avoid water leaking to the outside. A continuous pressure head of 1 cm water is applied to the surface of the column. The percolation or "subsurface infiltration" is recorded accurately with a buret that supplies the water for percolation while maintaining the pressure head of 1 cm. Recording was continued until a constant percolation rate was observed.

The results are:
- site P6 (mapping unit B3 II SO) a percolation of 4.5 mm/hr in the period 20-180 min after start,
- site P12 (mapping unit B3 II SO) 2 mm/hr immediately after the start,
- site P20 (B3 I SO) about 6 mm/hr in the period 10-90 min after start.

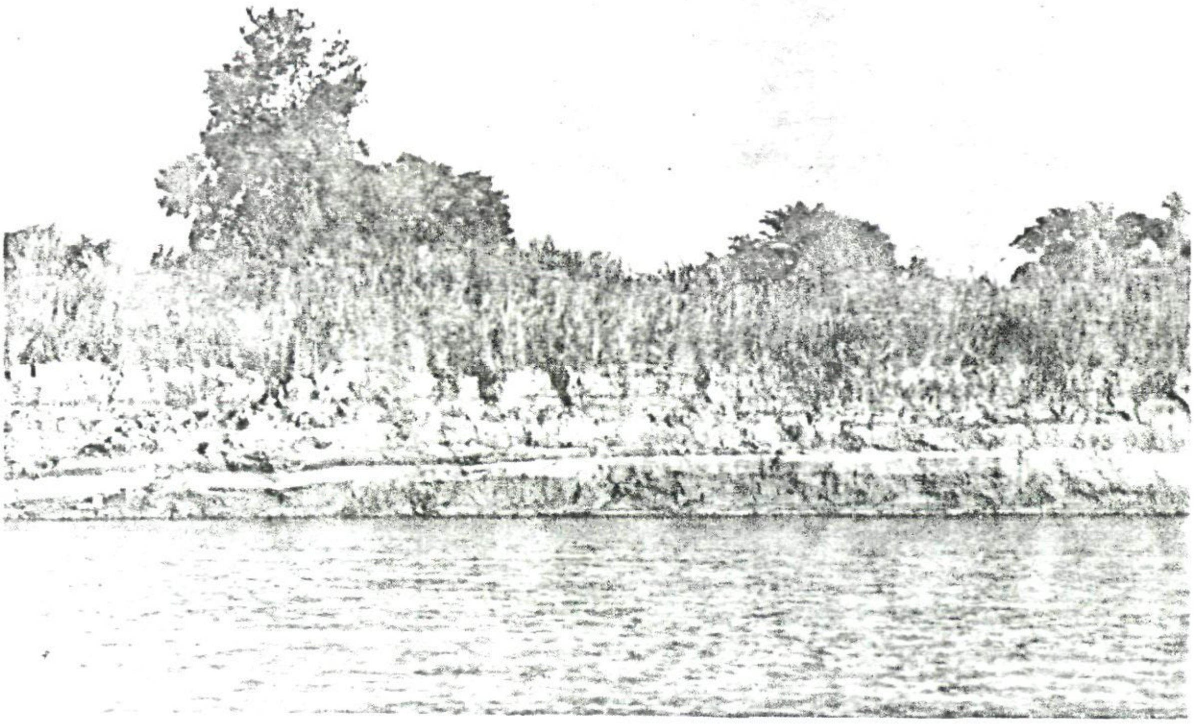


Fig. 4.01 Stratified levee of the Tana river

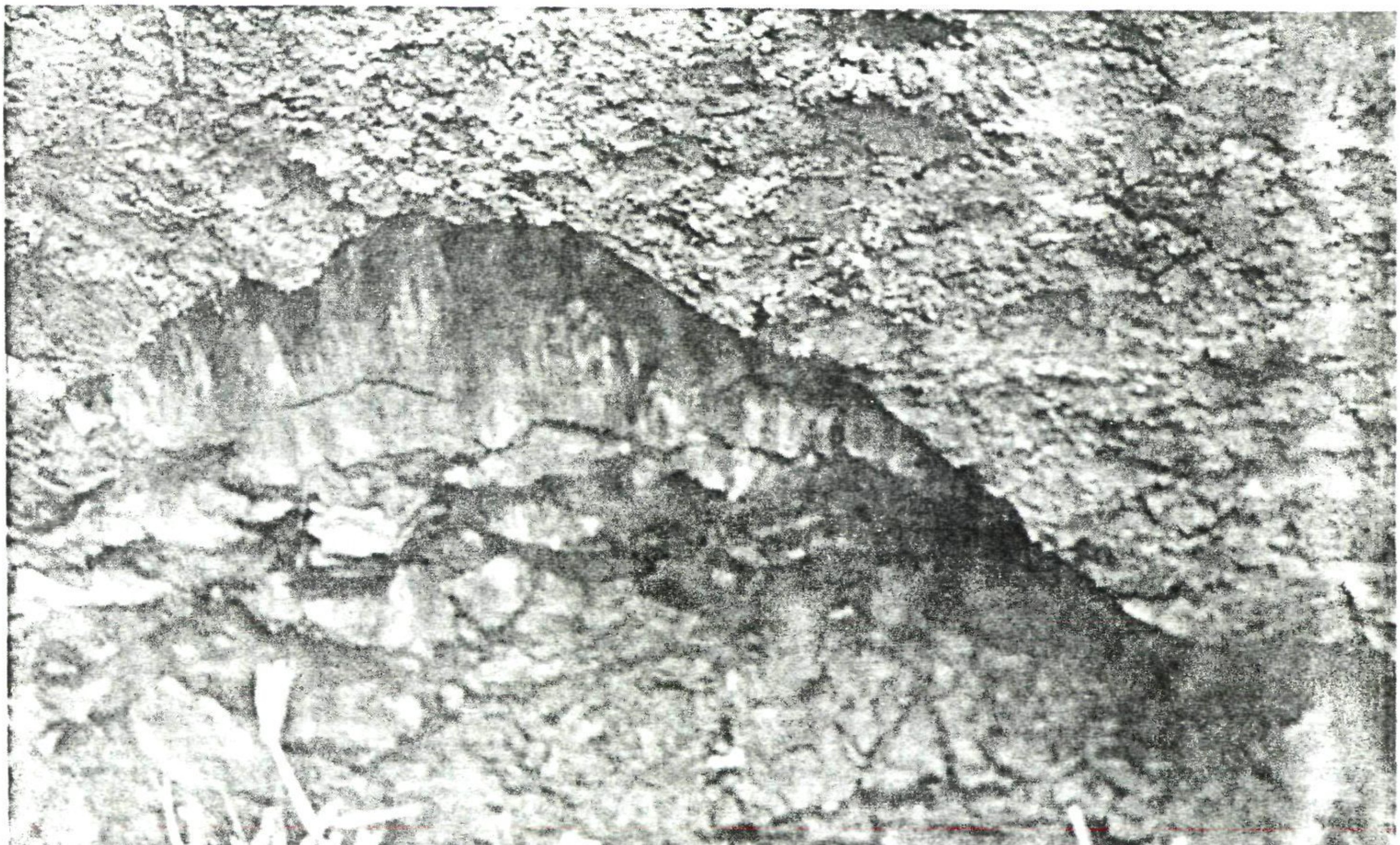


Fig. 4.02 Slickensides, polished and grooved surfaces produced by one soil mass sliding past another, are common features in the swelling river basin clay soils Photograph from 60 - 80 cm depth

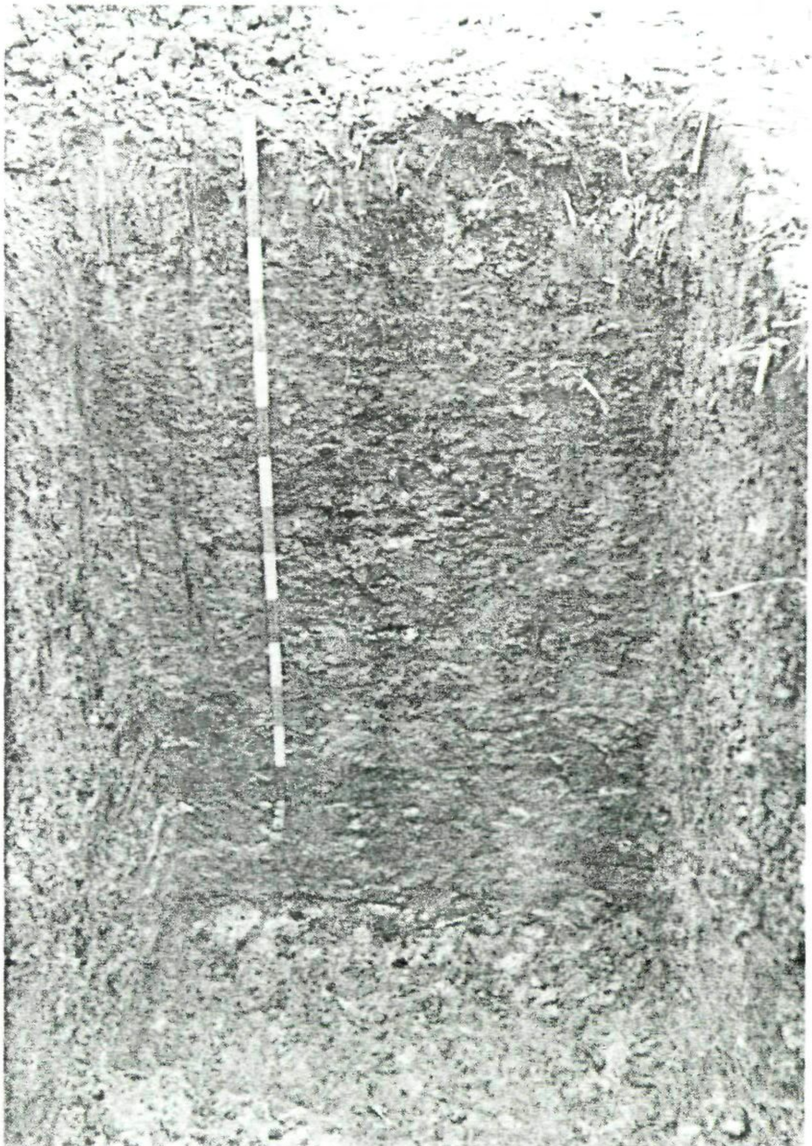
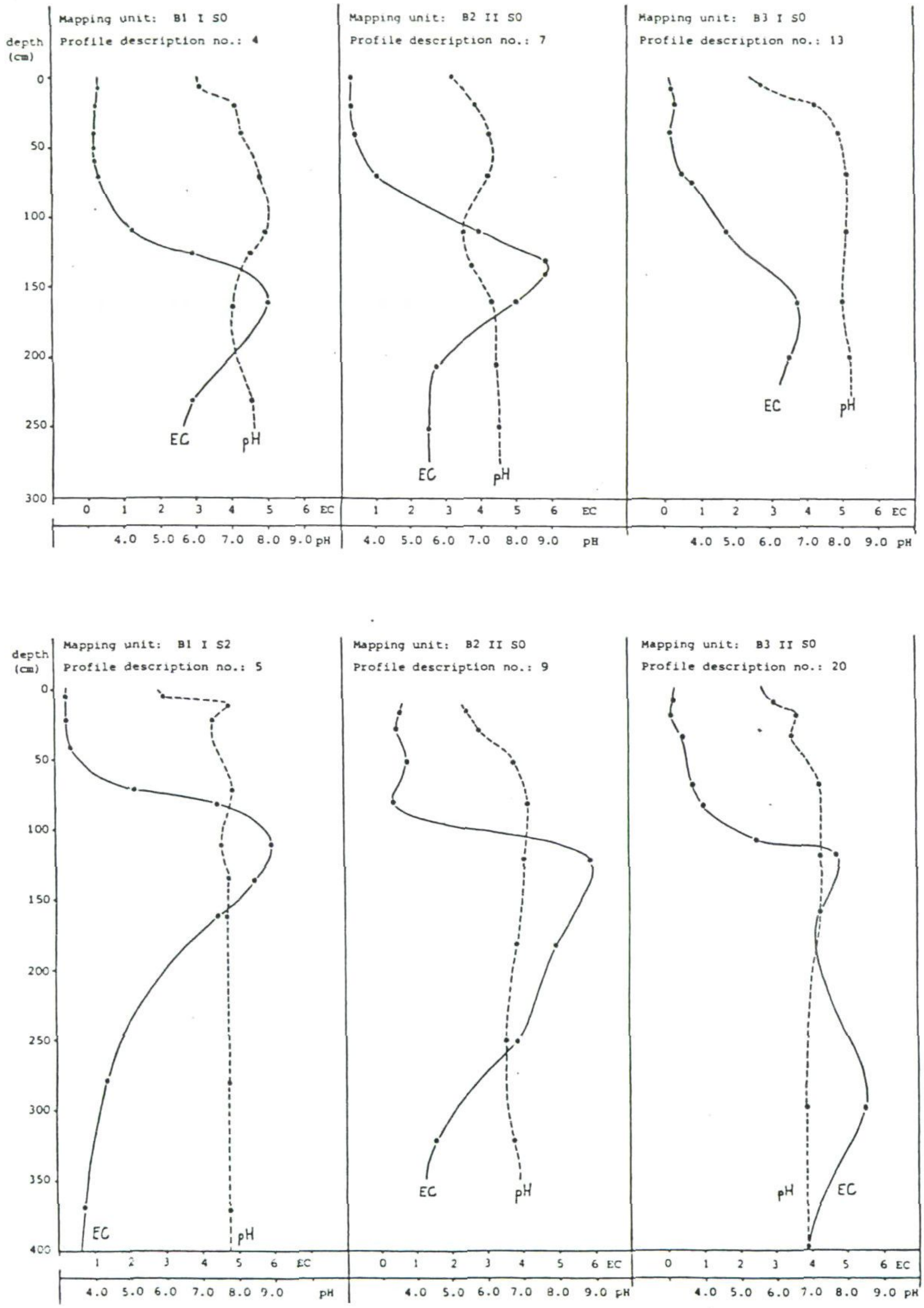


Fig. 4.03 Homogeneous clay soil of mapping unit B3IISO; non-saline; suitability class 1

Fig. 4.04 Dense grass vegetation on basin-over-levee soils; unit $\frac{B}{L}2$

Fig. 4.05 Soil material from an augerhole in a basin-over-terrace soil; basin clay in the lower file, terrace material upper right, characterized by many coarse $CaCO_3$ concretions



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Salinity EC (1 : 2.5 v/v) mS/cm and pH-H_2O (1 : 2.5 v/v) in 6 representative soil profiles

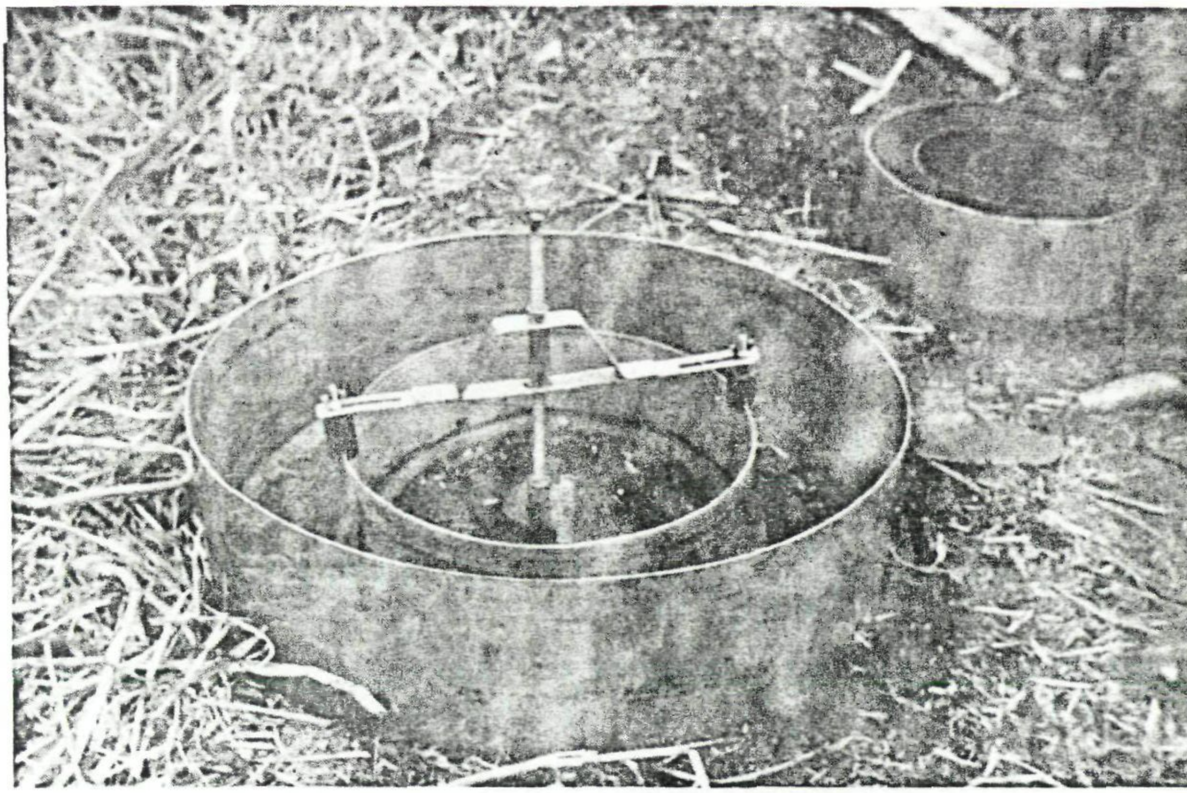


Fig. 4.07 Set-up of the infiltration measurement in duplo with the double ring method

Fig. 4.08 Set-up the measurement of the hydraulic conductivity (foreground) In the background the double ring for the infiltration measurement

5. LAND SUITABILITY FOR LARGE-SCALE IRRIGATED RICE

5.1 Classification system

The land classification system of the Bureau of Reclamation of the U.S. Department of the Interior has been adopted in many countries for the classification of irrigated land. The direct application of this sytem in Kenya is hampered by the lack of economic data. The Kenya Soil Survey has modified this system to allow for the conditions in Kenya (Muchena, 1981). The proposed criteria for land suitability classification for irrigation, as written down in this publication are used in principal for this study. Modifications are made to allow for soil conditions in the project area.
Several suitability criteria, are comparable to those of the detailed reconnaissance survey for the Lower Tana Village Irrigation Programme. The land suitability classes are based on the physical and chemical constraints of the area.

To determine the suitability of the various mapping units, first the limitations in soil and land qualities are evaluated and subsequently compared with the minimum criteria of the various suitability classes (Table 5.01).

5.2 Land suitability classes

The appraisal of the suitability is carried out, assuming that:

- flood control works are constructed, in order to prevent both the area from flooding and erosion
- sufficient irrigation water of good quality is transported to the areas concerned. Irrigability is therefore not considered in the appraisal
- adequate measures are taken to remove drainage water and excess irrigation water. Drainability is therefore not considered in the appraisal
- adequate measures are taken to prevent soils from salinization when cultivated.

Four suitability classes are distinguished (Table 5.02).
Classes 2, 3 and NS (unsuitable) are subdivided according to the main limiting factor(s).

A main limiting factor which represents only a minor limitation and which does not determine the suitability class, is indicated in brackets. This is particularly relevant for suitability class 1. The factors and their codes are given in Chapter 5.3 and in Tabel 5.02. It should be kept in mind that the suitability presented is only valid for irrigated rice.

5.3 Land qualities and specific criteria

5.3.1 General

Rice is a crop which requires a number of special conditions, which have to be considered when the suitability of the land is evaluated.
Requirements are:

- a slowly permeable soil, or a soil that can be made slowly permeable because rice should be partly submerged when growing
- a level topography for uniform distribution of water. This is of particular importance when large-scale cultivation is planned
- no salinity in the rooting zone, to a depth of approximately 20-40 cm. Rice is known to grow on soils with a saline subsoil at shallow depths, but this needs special management practices and much experience. Moreover, under these conditions a relatively high and continuous water supply is required and even then yields are not optimal
- no alkalinity or extreme acidity within 50 cm depth because these restrict the effective rooting depth.

The following land qualities, which determine the suitability of land for large-scale irrigated rice, were considered:

soil texture
soil depth
hydraulic conductivity
soil reaction
soil salinity
soil sodicity
topography
vegetation
soil pattern

In the next paragraphs the above mentioned land qualities are dealt with in further detail.

5.3.2 Soil texture, soil depth and hydraulic conductivity

(soil texture indicated in the suitability class with code "z". It may also form part of code u in suitability class NS with the other limiting factors)

These qualities are dealt with here together, because in the project area they are very much related.

Rice is grown on soils that are slowly permeable or that can be made slowly permeable. Soils that consist of clay to a certain depth respond in general to this condition. The hydraulic conductivity in the basin area is slow (Chapter 4.7.3) if the clay soil is moist or wet. The soils of the river levee land consist largely of stratified sand and clay. The hydraulic conductivity of these soils is higher due to the rapid permeability of the sandy layers.

Control of the irrigation water is more difficult to achieve and seepage may occur. To prevent these unfavourable conditions the soil has to respond to soil texture criteria. The texture criteria deal with the particle size fraction and thickness (Table 5.01). Also the texture of the subsoil is considered. The presence of stratified sand and clay may increase the costs for development; for instance a necessary lining of some parts of the irrigation canals to prevent seepage. This soil quality is a minor limiting factor, therefore indicated in brackets (Table 5.02). In addition, for large-scale cultivation of irrigated rice, the hydraulic conductivity has to be slow (Table 5.01). Soil depths meet the criteria, mentioned in Table 5.01; all soils in the project area are very deep (depths greater than 1.20 m).

5.3.3 Soil reaction

Values of pH 5.5 to 6.5 in the rooting zone of soils for rice are most common. These values become higher under flooded conditions. Rice can be grown on soils with a pH of 8 or more, however, with moderate success. Production is considerably reduced in soils with a pH lower than 4. The pH of the soils in the project area is in general between 5.5 and 8. Higher values occur only locally.

The minimum requirements are mentioned in Table 5.01. They deal only with limitations because of alkalinity. Limitations because of acidity are not relevant for this area.

5.3.4 Soil salinity (limiting factor indicated in the suitability classes with code "s")

Soil salinity is an important characteristic for the evaluation of the suitability of the land. The yield of rice decreases with increasing salinity of the rooting zone; an ECe-value of 5 mS/cm gives a decrease of 10%, ECe-value of 6 mS/cm a decrease of 25% and an ECe-value of 8 even 50% (ILRI, 1974).

Much attention is therefore given to the EC-values of the soils (see also Chapter 4.3.2 and 4.6.2).

The minimum salinity criteria, given in Table 5.01, largely correspond with those given by KSS (Muchena, 1981), but are adapted to the salinity conditions prevailing in the project area.

5.3.5 Soil sodicity (limiting factor indicated in the suitability class with code "d")

Sodic material has an adverse effect on the chemical and physical condition of a soil. The relatively high sodium content on the exchange complex adversely influences the nutrition status of the soil. More important however is the easy dispersion of the clay because of the high sodium content on the exchange complex. Structure stability of this soil material is low and difficulties may be expected in construction of canals and drains when present at shallow depths. The minimum criteria are mentioned in Table 5.01. The estimation of the sodicity is complicated. The approach is discussed in Chapter 4.6.3.

5.3.6 Topography (limiting factor indicated in the suitability classes with code "t")

Limiting topographic factors are derived from the macro topography (slope) and meso- and microrelief.

Slope deals with differences in topography over larger distances, mainly expressed by the length and steepness of the slope. Within the project area slope is not a limiting factor in the land appraisal. The basin land is flat; in the river levee land there are very few places where the slope exceeds two per cent and these are usually short, steep slopes adjacent to or into old river channels.

Mesorelief concerns medium sized differences in topography over rather short distances. It takes into account the surface features occurring within the general macrorelief. It is mostly related to sedimentation and, in the project area to a minor extent, with erosion processes; river levees, channels, depressions, gullies. The presence of a fine network of shallow gullies and depressions in the almost flat areas is a limitation for large-scale rice irrigation development because of the necessary levelling. The extent of this type of mesorelief in the project area is limited (relief class III on the soil map).

Microrelief is characterized by relief irregularities and undulations found within short distnaces, such as gilgai, cowfoetoes and tussocks. These minor undulations are not considered to be a limitation. As for the gilgai, this microrelief feature is present almost everywhere because of the swelling and shrinking property of the clay that is present in the majority of the soils. This may imply that some levelling is required annually.
The criteria for the factor topography are given in Table 5.01.

5.3.7 Vegetation (limiting factor indicated in the suitability classes with code "T")

The density and type of vegetation on the land indicates the degree of clearing needed for reclamation. Vegetative cover varies from non-restrictive (grasslands) to severely restrictive (riparian forest). In the river basin land there are a few patches with forest.

Table 5.01 gives the minimum requirements for the suitability classes. Soils of the river levee land are in places covered with riparian forest. The appraisal of the soils of the river levee land however does not distinguish these areas because the main limiting factor is the soil texture in these soils. So this limiting factor is part of the undifferentiated set ("u") of limiting factors for these areas too.

5.3.8 Soil pattern (limiting factor indicated in the suitability class with code "p")

Soil pattern refers to the complexity of an area; the soils, in particular the soil texture, vary at short distances. As already mentioned in Chapter 5.3.1 large-scale rice cultivation requires a homogeneous soil over some extent. The ratio and the character of the occurring soils determines the degree of limitations. This limiting factor therefore is not specified in Table 5.01. The appraisal for large-scale irrigated rice takes this soil pattern factor into account in one area only.

5.4 Results of the land suitability classification

The main results of the appraisal of the soils for large-scale irrigated rice are presented in Table 5.03. This tabel summarizes the results of the appraisal of each soil mapping unit in Table 5.04.

The spatial extent of the land suitability classes is indicated in Figure 5.01. This figure is derived from the land suitability map (map 1.02).

Table 5.03 Land suitability classes for large-scale irrigated rice

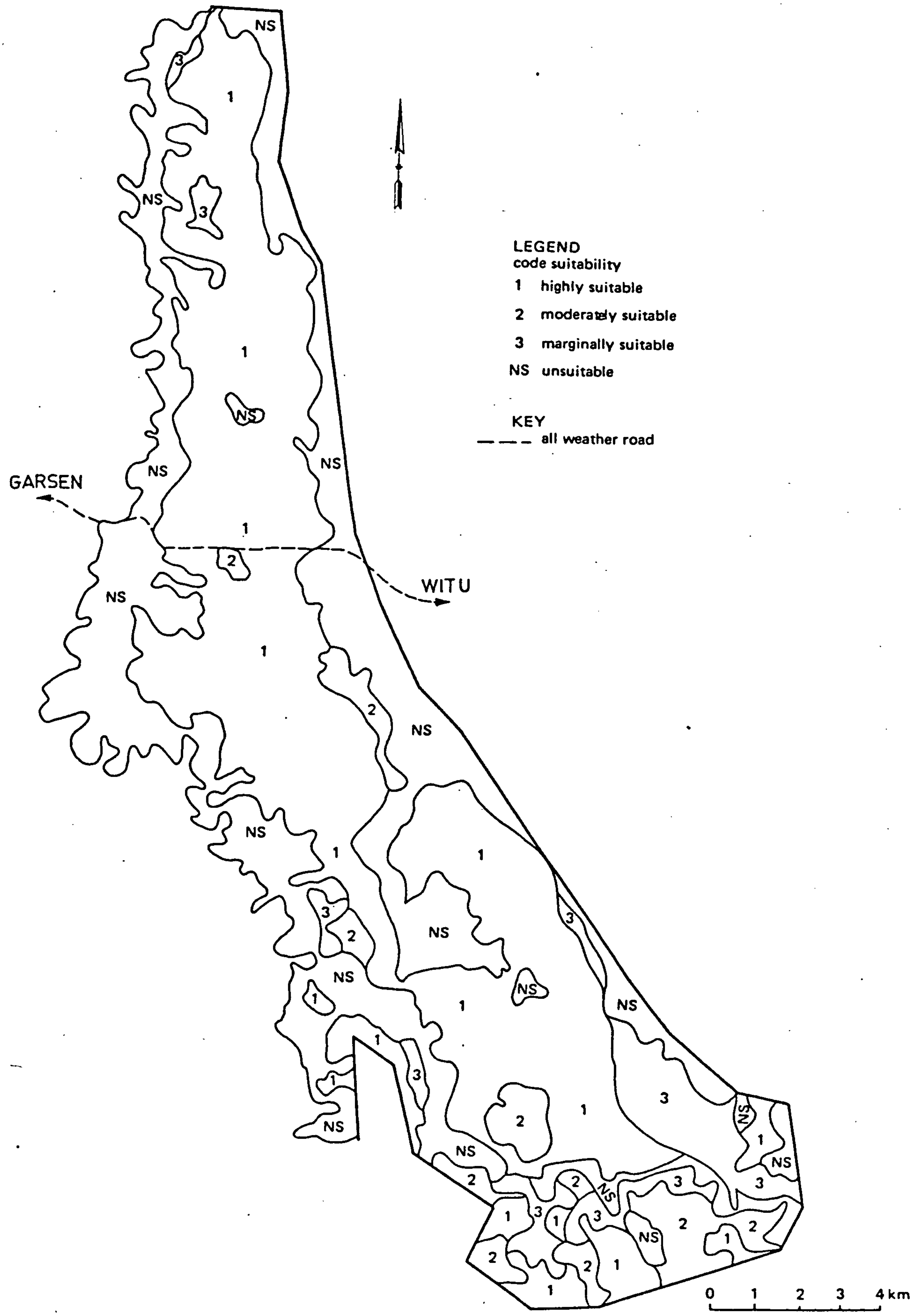
Suitability class	Description of class	Limitations	Area (ha)
1	highly suitable	none to minor	7910
2	moderately suitable	slight to moderate	1100
3	marginally suitable	moderate to severe	1380
NS	unsuitable	-	5280

Class 1 consists of land that is highly suitable for irrigated rice production. Minimum costs are expected for development and management associated with the land. Class 1 comprises deep basin soils which are non-saline throughout or slightly saline in the subsoil. These areas have a flat relief and in places a wide network of shallow depressions (6,185 ha). Non-saline, levee clay soils adjacent to river basin soils are included in this class (170 ha). The relatively low-lying area with Vertisols south of Moa in Terrace land (105 ha) is also considered highly suitable. The non-saline basin-over-levee soils (990 ha) and basin-over-terrace soils (460 ha) have minor limitations but are also classified as class 1 soils. Layers with sand in the basin-over-levee soils, usually occurring deeper than 1 m, may affect the costs of development, because lining of canals may be necessary in some places (seepage). The easily dispersing soil material in the subsoil of the basin-over-terrace soils implies that difficulties in construction of canals may be expected in certain places.

Class 2 consists of land of moderate productivity due to slight to moderate limitations in soil qualities or moderate costs for development. This class includes river basin soils and levee clay soils with a non-saline topsoil but with a moderately saline subsoil deeper than 40-70 cm (780 ha). An area non-saline deep basin soils (320 ha) requires levelling due to a very gently undulating mesorelief and a rather dense network of predominantly shallow depressions.

Class 3 consists of land with a restricted productivity for irrigated rice due to moderate to severe limitations in soil qualities. Relatively high costs for development (i.e. levelling and clearing) are associated with this class. Class 3 (1,380) ha) comprises a large variety of soils. An area of 105 ha of deep basin soils is marginally suitable due to saline soil material at shallow depths. Relatively high costs for clearing and levelling may be expected in 240 ha of deep basin soils covered by forest and desected by gullies. As these soils are likely to be similar to those of the adjacent non-forested basin land no major soil deficiences are expected. Levee soils that consist of clay to clay loam, in places over stratified, fine sandy, micaceous soil material cover 210 ha. The main limitations for these soils are the presence of sand layers and often moderately saline soil material starting at 40-70 cm depth. The limitation of the basin soils association (140 ha) is the variability over short distances; deep basin soils alternate with soils that have a layer of medium fine sand over clay. The main limitation in a relatively low-lying area on Terrace land (680 ha), situated west and north-west of Moa village is the presence of easily dispersing soil material (old alluvial deposits), starting at 20-70 cm below the surface. Because of the low structure stability of this soil material at shallow depths, difficulties may be expected in construction of canals and drains.

Class NS includes land that does not meet the minimum requirements for the other land suitability classes. The main limitation for most of the soils in river levee land and crevasse splays (4,010 ha) is the irregular pattern of stratified sand material. This implies an unfavourable and often unexpected drainage pattern. In addition, the topography would require expensive levelling. Some 50 ha river basin land is unsuitable due to moderately to strongly saline soil material, starting at very shallow depth. An area of 20 ha wooded basin-over-levee soils along a former river course is included in this class. Soils on the old alluvial deposits of Terrace land are in general unsuitable mainly due to salinity and sodicity at shallow depths. The area of these soils is included in the map because of map presentation (1,200 ha).



HASKONING BV

Mwenge International Associated Limited

fig: 5.01

title: GENERALIZED LANDSUITABILITY MAP

TABLE 5.01

LAND CLASSIFICATION CRITERIA FOR LARGE-SCALE IRRIGATED RICE, NOT CONSIDERING IRRIGABILITY AND DRAINABILITY
Specification for Tana Delta Irrigation Project

Land characteristics / Land suitability class		Class 1	Class 2	Class 3	Class NS
Soil texture (z)		clay to clay loam over clay (within 50 cm)	clay to clay loam over clay (within 50 cm)	clay to clay loam over clay loam (within 50 cm)	Class NS includes land that does not meet the minimum requirements for the other land classes
Soil depth		90 cm plus	90 cm plus	90 cm plus	
Hydraulic conductivity		slow	slow	slow	
Soil reaction		pH-H_2O <8.5 to at least 80/100 cm depth	pH-H_2O <8.5 to at least 80/100 cm depth	pH-H_2O <8.5 to at least 50 cm depth	
Soil salinity (<100 cm depth) (s)		0-40/70 cm non-saline 40/70-100 cm non-saline or slightly saline	- 0 - 40/70 cm non-saline - 40/70 - 100 cm moderately saline - 0 - 20/40 cm non-saline or slightly saline 20/40 - 100 cm slightly saline	0 - 20/40 cm non-saline 20/40 - 40/70 cm slightly saline 40/70 - 100 cm moderately saline	
Soil sodicity (d)		0 - 40/50 cm non-sodic 40/50 - 80/100 cm non-sodic to moderately sodic (ESP <15%)	0-40/50 cm non-sodic 40/50 - 80/100 cm non-sodic to moderately sodic (ESP <15%)	0 - 40/50 cm non- to slightly sodic > 40/50 cm moderately to strongly sodic	
Topography (t)	slope	< 1%	< 1%	< 2%	
	meso- and micro relief	smooth, except for gilgai and minor undulations	somewhat irregular (<4/5 dm); smooth, except for gilgai and minor undulations	slightly irregular (<1m) but no major gullies or dissections	
Vegetation (1)		up to moderate bush; woody cover less than 20%	up to moderate to thick bush with high palms; woody cover less than 40%	up to dense bush and thicket, but excluding continuous high woodland/forest; woody cover less than 80%	

Table 5.02

Suitability classes; general description and indication of main limiting factor(s)

Suitability class	Description	Suitability class with main limiting factor(s)*
1	Highly suitable Land suitable for sustained irrigated rice production; minimum costs of development and management associated with the land	1 1(t) 1(z) 1(d) 1(t.z) 1(t.d)
2	Moderately suitable Land of moderate productivity; slight to moderate limitations in soil qualities or requiring moderate costs for development	2t 2s 2s(t) 2s.t
3	Marginally suitable Land of restricted productivity for irrigated rice; moderate to severe limitations in soil qualities and - in addition - requiring relatively high costs for development (i.c. levelling) or requiring relatively high costs for levelling and clearing	3s 3p.z 3T 3d 3z 3zs
NS	Unsuitable Land which is unsuited to sustained irrigated rice production; severe limitations in soils, topography and/or vegetation cover	NStT NSs NSu

Key of codes for main limiting factors*

d	soil sodicity
p	soil pattern
s	soil salinity
t	topography
T	vegetation
u	one ore more limiting factors undifferentiated
z	soil texture

* A main limiting factor which represents only a minor limitation and which does not determine the suitability class is indicated in brackets.

Table 5.04 Soil mapping units and land suitability for large-scale irrigated rice

Soil mapping unit	Suitability class	Extent ha	Extent %
	1 HIGHLY SUITABLE		
B1 I S0, B1 I S0/S1, B1 I S1, B2 I S0, B2 I S1, B3 I S0, B3 I S1, L4 I S0, T0 b	1	2215	14.2
B1 II S0, B1 II S0 b, B1 II S1, B2 II S0, B2 II S1, B3 II S0, B3 II S1, L4 II S0	1(t)	4245	27.1
$\frac{B2}{L}$ I S0	1(z)	80	0.5
$\frac{B1}{T}$ I S0, $\frac{B1}{T}$ I S1, $\frac{B2}{T}$ I S0, $\frac{B3}{T}$ I S0	1(d)	360	2.3
$\frac{B2}{L}$ II S0, $\frac{B3}{L}$ II S0	1(t.z)	910	5.8
$\frac{B2}{T}$ II S0	1(t.d)	100	0.6
	Total class 1	7910	50.5
	2 MODERATELY SUITABLE		
B2 III S0, B3 III S0	2t	320	2.0
B1 I S2, B2 I S2, L4 I S2	2s	415	2.6
B2 II S2	2s(t)	325	2.1
B2 III S2	2s.t	40	0.3
	Total class 2	1100	7.0
	3 MARGINALLY SUITABLE		
B1 I S3	3s	105	0.7
B1/$\frac{L}{B}$ II S0	3p.z	140	0.9
B1 I S0 f, B2 II S0 f, B3 II S0 f	3T	240	1.5
T02	3d	680	4.3
L3 II S0	3z	40	0.3
L3 II S2	3z.s	175	1.1
	Total class 3	1380	8.8
	NS UNSUITABLE		
$\frac{B2}{L}$ II S0 f	NStT	20	0.1
B2 II S4	NSs	50	0.3
L1, L2 I, L2 II, L3 II S0 f, L3 II S0 b, L3 II S2 b, T01	NSu	5210	33.3
	Total class NS	5280	33.7

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Survey of Kenya	1963	Series Y633 maps at scale 1:100 000 Sheet no. 168 (Manzini). Survey of Kenya, Nairobi.
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APPENDIX 1

Description and analytical data of representative soil profiles

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 1

Observation no.: P15

Soil classification: vertic FLUVISOL saline-sodic phase

Mapping unit: L4 I S2

Horizon	A1	C1	C2	C3	C4
Depth of sample (cm)	5-10	25-35	80-90	120-130	160-170
TEXTURE					
Sand % 2.0 - 0.05 mm	14	18	16	12	16
Silt % 0.05 - 0.002 mm	18	18	18	24	18
Clay % 0.002 - 0 mm	68	64	66	64	66
Texture class	C	C	C	C	C
CHEMICAL DATA					
pH-H_2O (1:2.5 v/v)	7.3	7.0	7.2	7.1	6.8
pH-KCl "	7.2	6.0	6.1	6.0	5.2
EC (mS/cm) "	0.45	0.45	6.00	4.50	4.50
$CaCO_3$ (%)	0.16	0.16	1.00	0.13	0.20
$CaSO_4$ (%)	trace	0.14	0.31	0.70	0.80
C (%)	0.82	0.93	0.38	0.23	0.17
N (%)					
C/N					
CEC (me/100g), pH 8.2	44.6	55.6	55.6	48.5	51.9
Exch. Ca (me/100g)	28.0	28.0	30.0	27.0	28.0
" Mg "	16.8	16.0	21.5	24.0	27.5
" K "	1.3	1.1	0.9	1.0	0.9
" Na "	2.1	4.8	12.7	14.4	21.5
Sum of cations	48.2	49.9	65.1	66.4	77.9
Base sat. %, pH 8.2	>100	90	>100	>100	>100
ESP at pH 8.2	5	9	23	30	41
Saturation extract:					
Moisture %		80	98	103	
pH-paste		7.7	7.5	7.6	
ECe (mS/cm)		0.50	7.50	10.0	

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	19.8
Mg "	8.4
K "	0.86
Na "	1.26
P (ppm)	40
Mn (me/100g)	0.58
Exch. acidity (me/100g)	
pH-H_2O (1:1 v/v)	5.8
C %	1.43
N %	0.17

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	5-10	7.2	0.4
	20	7.3	0.5
C1	25-35	7.8	0.5
	40	7.7	1.0
	70	7.1	3.9
C2	80-90	7.0	9.0
	110	7.1	8.0
C3	120-130	7.2	8.0
C4	160(160-170)	7.2	7.0
	300	7.1	6.0
	500	7.2	6.0
groundwater		6.5	27

Profile description no. 1

Observation/date : P15; approx. 0.75 km south of Galili; 9/10/'81

Mapping unit : L4 I S2

Physiography : Floodplain; River levee land

Topography : flat; weak gilgai microrelief

Salinity/sodicity : slightly saline from 50 cm, moderately saline from 115 cm; sodic from 50 c

Vegetation : grasses and some sedges

Drainage conditions: moderately to imperfectly drained; seasonally flooded up to 0.3 m; groundwaterlevel at 4.80 m (Sept. 1981).

Profile description:

A_1 0-15 cm dark brown (7.5 YR3/1 moist); humic clay; moderate, coarse prismatic structure, breaking into weak, fine subangular and angular blocky structure; few, thin slickensides; very hard when dry, firm when moist, sticky and plastic when wet; few, fine, faint iron mottles; common, fine roots; gradual, wavy transition to

C_1 15-50 cm dark brown (7.5 YR3/1 moist); clay; moderate, coarse prismatic structure, breaking into moderate, fine subangular and angular blocky structure; common, medium slickensides; very hard when dry, firm when moist, sticky and plastic when wet; few, fine, distinct iron mottles; few, fine roots; gradual, wavy transition to

C_2 50-115 cm dark brown, (7.5 YR3/2 moist); clay; moderate, medium angular blocky structure; abundant, thick slickensides; firm when moist, very sticky and plastic when wet; few, fine, faint iron mottles; few, very fine roots; few (2%), fine (2mm) manganese concretions; clear smooth transition to

C_3 115-145 cm very dark grayish brown (10 YR3/2 moist); clay; moderate, fine, angular blocky structure; abundant, medium slickensides; firm when moist, sticky and plastic when wet; few, fine, faint iron mottles; many (5%), fine (2mm) carbonate concretions and few (1%), fine (1mm) manganese concretions; clear, smooth transition to

C_4 145-240 cm very dark grayish brown (10 YR3/2 moist); clay; weak, fine angular blocky structure; common, medium slickensides; firm when moist, stick and plastic when wet; few, fine, faint iron mottles; few (2%), fine (2mm) manganese concretions; type of transition not observed because of augering from 180 cm onwards

C_5 240-300 cm dark grayish brown (10 YR4/2 moist); clay; firm when moist, very sticky and plastic when wet; common, fine, faint iron mottles; few (2%), fine (2mm), manganese concretions

C_6 300-440 cm dark grayish brown (10 YR4/2 moist); clay; firm when moist, very sticky and plastic when wet; many, medium, distinct iron mottles; few (1%), fine (2mm), manganese and few, medium (5mm) carbonate concretions

C_7 440-500 cm very dark grayish brown (10 YR3/2 moist); sandy clay loam; firm when moist, slightly sticky and slightly plastic when wet; many, medium, distinct iron mottles; few (1%), fine (1mm) manganese concretions; micas

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 2

Observation no.: P1 Soil classification: vertic FLUVISOL

Mapping unit: B1 I SO

Horizon	A11	A12	C1	C2	C3
Depth of sample (cm)	0-5/10	5-10/25	25-75	75-140	140-175
TEXTURE					
Sand % 2.0 - 0.05 mm	12	14	16	16	18
Silt % 0.05 - 0.002 mm	8	14	24	14	12
Clay % 0.002 - 0 mm	80	72	60	70	70
Texture class	C	C	C	C	C
CHEMICAL DATA					
pH-H_2O (1:2.5 v/v)	6.5	6.6	7.2	7.6	6.9
pH-KCl "	5.4	5.4	5.9	6.5	6.3
EC (mS/cm) "	0.42	0.4	0.63	0.95	0.9
$CaCO_3$ (%)	1.29	1.04	0.68	1.84	2.18
$CaSO_4$ (%)	tr.	tr.	tr.	tr.	tr.
C (%)					
N (%)					
C/N					
CEC (me/100g), pH 8.2	53.0	49.0	43.2	47.3	51.4
Exch. Ca (me/100g)	21.2	26.5	26.5	26.9	21.5
" Mg "	8.1	9.2	9.6	11.8	13.9
" K "	2.0	1.6	1.0	0.9	0.9
" Na "	1.7	1.8	1.7	2.8	5.0
Sum of cations	33.0	39.1	38.8	42.4	40.3
Base sat. %, pH 8.2	62	80	90	90	80
ESP at pH 8.2	3	4	4	6	10
Saturation extract:					
Moisture %				101.6	104.4
pH-paste				7.3	7.7
ECe (mS/cm)				0.9	1.0

FERTILITY ASPECTS: (depth in cm)	0-5/10	5-10/25
Ca (me/100 g)	13.4	15.0
Mg "	8.6	9.7
K "	0.74	0.48
Na "	0.80	0.71
P (ppm)	36	32
Mn (me/100g)	0.63	0.39
Exch. acidity (me/100g)		
pH-H_2O (1:1 v/v)	5.6	5.8
C %	1.32	1.15
N %	0.17	0.16

no laboratory data are available

Profile description no. 2

Observation/date : P1; 0.07 km east of Wema-Kulesa track and approx. 0.6 km south of Kulesa village; 26/1/'81 (Grabowsky & Poort, 1981)

Mapping unit : B1 I SO

Physiography : Floodplain;River basin land, moderately high

Topography : flat; weak gilgai microrelief

Vegetation : grasses

Salinity/sodicity : non-saline ; non-sodic

Drainage conditions: moderately well drained

Profile description:

A_{11}	0-5 cm	reddish brown (5 YR4/3 dry); dark reddish brown (5 YR3/3 moist); clay; strong, fine, subangular blocky structure; hard when dry, firm when moist, very sticky and plastic when wet; common, fine roots; few (1%), fine (1 mm), manganese concretions; abrupt, wavy transition to
A_{12}	5-25 cm	dark brown (7.5 YR3/1 dry); clay; strong, fine to coarse subangular blocky structure; hard when dry, firm when moist, very sticky and plastic when wet; few, fine, distinct iron mottles; few, medium roots; few (1%), fine (1 mm) manganese concretions; clear, wavy transition to
C_1	25-75 cm	dark brown (7.5 YR3/2 dry); clay; very strong, very coarse prismatic structure; very hard when dry, very firm when moist, very sticky and plastic when wet; few, fine, faint iron mottles; few, medium roots; few (1%), fine (1 mm) manganese concretions; clear, wavy transition to
C_2	75-140 cm	dark brown (7.5 YR3/2 moist); clay; strong, very coarse prismatic structure; abundant, thick slickensides; very firm when moist, very sticky and plastic when wet; few, medium roots extending to approximately 100 cm; few (1%), fine (2 mm) manganese concretions; gradual, wavy transition to
C_3	140-175 cm	very dark grayish brown (10 YR3/2 moist); clay; moderate, coarse angular blocky structure; abundant, thick slickensides; very firm when moist, very sticky and plastic when wet; few (1%), small (1 mm) manganese concretions; type of transition not observed because of augering from 175 cm onwards
C_4	175-400 cm	dark grayish brown (10 YR4/2 moist); clay; very firm when moist, very sticky and plastic when wet; few, fine, faint iron mottles; few (1%), fine (1 mm) manganese concretions; some gypsum crystals.
C_5	400-440 cm	dark gray (5 Y4/1 moist); clay; firm when moist, very sticky and plastic when wet; common, medium, faint iron mottles
C_6	440-500 cm	dark gray (2.5 Y4/1 moist); clay; firm when moist, very sticky and plastic when wet; few, medium, faint iron mottles; common (3%), fine (1 mm) manganese concretions

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 3

Observation no.: P3 — Soil classification: Vertic FLUVISOL, sodic phase

Mapping unit: B1 I SO

Horizon	A11	A12	C1	C2	C3
Depth of sample (cm)	0-8	8-31	31-44	44-115	115-160
TEXTURE					
Sand % 2.0 - 0.05 mm	16	16	14	26	18
Silt % 0.05 - 0.002 mm	14	18	20	22	16
Clay % 0.002 - 0 mm	70	66	66	52	66
Texture class	C	C	C	C	C
CHEMICAL DATA					
$pH-H_2O$ (1:2.5 v/v)	6.7	7.2	7.6	7.1	7.3
pH-KCl "	5.3	5.9	6.1	6.1	6.2
EC (mS/cm) "	0.4	1.2	0.4	2.5	2.1
$CaCO_3$ (%)	0.88	1.76	1.29	1.55	2.07
$CaSO_4$ (%)	trace	tr.	-	0.56	tr.
C (%)	1.75	0.43			
N (%)	0.22	0.09			
C/N					
CEC (me/100g), pH 8.2	56.5	53.5	50.2	39.5	49.0
Exch. Ca (me/100g)	24.5	24.5	24.5	28.3	24.6
" Mg "	9.6	12.9	10.8	12.7	14.1
" K "	1.8	0.8	0.7	0.5	0.7
" Na "	2.1	2.8	2.1	6.7	5.0
Sum of cations	38.0	41.0	38.1	48.2	44.4
Base sat. %, pH 8.2	67	77	76	>100	91
ESP at pH 8.2	4	5	4	17	10
Saturation extract:					
Moisture %	98.4	-	76.3	93.5	
pH-paste	7.5	-	7.0	7.3	
ECe (mS/cm)	1.6	-	1.1	4.0	

FERTILITY ASPECTS: (depth in cm)	0-8	8-31
Ca (me/100 g)	15.2	12.0
Mg "	8.6	11.2
K "	0.6	0.2
Na "	1.3	2.7
P (ppm)	38	40
Mn (me/100g)	0.52	0.41
Exch. acidity (me/100g)		
$pH-H_2O$ (1:1 v/v)	5.5	6.7
C %	1.75	0.43
N %	0.22	0.09

no field laboratory data available

Profile description no. 3

Observation/date : P3; approx. 1.5 km south of Kulesa village; 24/1/'81 (Grabowsky & Poort, 1981)

Mapping unit : B1 I SO

Physiography : Floodplain; River basin land; moderately high

Topography : flat; weak gilgai microrelief

Vegetation : grasses and some acacia trees

Salinity/sodicity : non-saline ; sodic from 44 cm

Drainage conditions : moderately well drained

Profile description:

A_{11}	0-8	cm	very dark gray (10 YR3/1 dry); clay; strong, fine to medium subangular blocky structure; very hard when dry, sticky and plastic when wet; abundant, fine and medium roots; few (1%), fine (2 mm) manganese concretions; clear, smooth transition to
A_{12}	8-31	cm	dark brown (7.5 YR4/2 dry); clay; strong, medium to coarse angular blocky structure; very hard when dry, sticky and plastic when wet; few, fine, faint iron mottles; abundant fine and medium roots; few (1%), fine (1 mm) manganese concretions; clear, smooth transition to
C_1	31-44	cm	dark brown (7.5 YR4/2 dry); clay; strong, coarse to very coarse angular blocky structure; common, medium slickensides; very hard when dry, sticky and plastic when wet; common fine and very fine roots; few (1%), fine (1 mm) manganese concretions; gradual, wavy transition to
C_2	44-115	cm	very dark grayish brown (10 YR3/2 dry); clay; strong, coarse to very coarse angular blocky structure; common, medium slickensides; very hard when dry, sticky and plastic when wet; few, fine, faint iron mottles; few (1%), fine (1 mm) manganese concretions; very few, very fine roots; gradual, wavy transition to
C_3	115-200	cm	very dark gray (10 YR3/1 dry); clay; strong, coarse, angular blocky structure; very hard when dry, firm when moist, sticky and plastic when wet; few, fine, faint iron mottles; very few, very fine roots extending to approximately 150 cm; few, (1%) fine (1 mm) manganese concretions and some gypsum crystals; type of transition not observed because of augering from 200 cm onwards
C_4	200-350	cm	dark grayish brown (10 YR4/2 moist); clay; firm when moist, sticky and plastic when wet; few, medium, distinct iron mottles; few (1%), fine (2 mm) manganese concretions
C_5	350-450	cm	dark grayish brown (10 YR4/2 moist); clay; firm when moist, sticky and plastic when wet; common, medium, distinct iron mottles; few (1%), fine (2 mm) manganese concretions

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 4

Observation no.: P5

Soil classification: vertic FLUVISOL

Mapping unit: B1 I SO

Horizon	A1	C1	C2	C2
Depth of sample (cm)	3-12	18-33	50-60	120-130
TEXTURE				
Sand % 2.0 - 0.05 mm	28	40	30	22
Silt % 0.05 - 0.002 mm	32	28	26	20
Clay % 0.002 - 0 mm	40	32	44	58
Texture class	C/CL	CL	C	C
CHEMICAL DATA				
pH-H_2O (1:2.5 v/v)	6.9	7.3	7.9	7.9
pH-KCl "	5.3	5.8	6.0	6.6
EC (mS/cm) "	0.22	0.20	0.29	1.10
$CaCO_3$ (%)	0.13	-	0.18	0.24
$CaSO_4$ (%)	trace	tr.	tr.	tr.
C (%)	1,14	0,26	0.41	0.29
N (%)				
C/N				
CEC (me/100g), pH 8.2	34.4	24.6	23.4	38.5
Exch. Ca (me/100g)	13.1	8,4	13.0	23.0
" Mg "	5.4	4.4	8.5	16.5
" K "	0.3	0.4	0.4	0.4
" Na "	0.8	0.6	1.3	7.8
Sum of cations	19.6	13.8	23.2	47.7
Base sat. %, pH 8.2	57	56	99	>100
ESP at pH 8.2	2	2	5	20
Saturation extract:				
Moisture %				53
pH-paste				7.5
ECe (mS/cm)				2.80
FERTILITY ASPECTS: (depth in cm)				
Ca (me/100 g)				
Mg "				
K "				
Na "				
P (ppm)				
Mn (me/100g)				
Exch. acidity (me/100g)				
pH-H_2O (1:1 v/v)				
C %				
N %				

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	5-12	6.1	0.3
	20	7.1	0.2
C1	18-33	7.1	0.3
	40	7.3	0.2
C2	50-60	7.3	0.2
	70	7.8	0.4
	110	7.9	1.2
C2	120-130	7.5	2.9
	160	7.0	5.0
	230	7.5	2.9
	460	7.7	2.1
groundwater		7.2	20

Profile description no. 4

Observation/date	: P5; along track Hewani-Wema, approx. 1 km north of turn-off to Hewani village; 7/9/'81
Mapping unit	: B1 I SO
Physiography	: Floodplain; River basin land; approx. 100 meter from former Tana course
Topography	: flat; weak gilgai microrelief
Vegetation	: grasses
Salinity/sodicity	: non-saline ; sodic from 120 cm
Drainage conditions	: moderately well drained; seasonally flooded up to 0.2 m; groundwaterlevel at 230 m

Profile description:

A_1	0-15 cm	black (N2 moist); humic clay; weak, coarse prismatic structure and moderate, fine to very fine angular and subangular blocky structure; very hard when dry, very firm when moist, sticky and plastic when wet; frequent, fine, roots; clear, smooth transition to
C_1	15-37 cm	dark grayish brown (10 YR4/2 moist); clay loam; strong, coarse angular blocky structure; very hard when dry, firm when moist, sticky and plastic when wet; many (>5%) micas; few, fine roots; clear, wavy transition to
C_2	37-200 cm	dark grayish brown (10 YR4/2 moist); clay; moderate, coarse angular blocky structure; abundant, thick slickensides; very firm when moist, sticky and very plastic when wet; few, very fine, faint iron mottles; few (2%), fine (2 mm) manganese concretions; micas; very few, very fine roots extending to approx. 100 cm; type of transition not observed because of augering from 160 cm onwards
C_3	200-250 cm	dark brown (10 YR4/3 moist); sandy clay loam; sticky and plastic when wet; few, fine, faint iron mottles
C_4	250-460 cm	dark grayish brown (10 YR4/2 moist); clay; sticky and very plastic when wet; from 400 cm and onwards few (1%), fine (2 mm) manganese concretions; micas

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 5

Observation no.: P11 Soil classification: vertic FLUVISOL, sodic phase

Mapping unit: B1 I S2

Horizon	A1	C1	C2	C3	C4	C5
Depth of sample (cm)	3-8	30-50	70-90	130-140	230-250	350-370
TEXTURE						
Sand % 2.0 - 0.05 mm	32	28	36	22	16	50
Silt % 0.05 - 0.002 mm	24	20	28	22	14	28
Clay % 0.002 - 0 mm	44	52	36	56	70	22
Texture class	C	C	CL	C	C	L
CHEMICAL DATA						
pH-H_2O (1:2.5 v/v)	5.8	7.8	7.5	7.9	8.0	8.5
pH-KCl "	4.6	6.1	6.3	6.8	6.9	7.1
EC (mS/cm) "	0.50	0.55	2.70	2.95	2.75	0.45
$CaCO_3$ (%)	0.08	0.13	1.00	0.30	0.28	0.10
$CaSO_4$ (%)	trace	tr.	1.20	tr.	tr.	tr.
C (%)	2.04	0.41	0.26	0.23	0.15	0.17
N (%)						
C/N						
CEC (me/100g), pH 8.2	39.0	40.4	30.5	48.9	58.5	16.3
Exch. Ca (me/100g)	18.4	17.0	42.0	44.0	33.0	10.0
" Mg "	11.7	16.5	17.5	24.0	26.5	11.7
" K "	1.3	0.9	0.9	1.5	1.9	0.4
" Na "	1.5	6.2	8.3	16.1	11.7	3.0
Sum of cations	32.9	41.2	66.7	85.6	72.6	25.1
Base sat. %, pH 8.2	84	>100	>100	>100	>100	>100
ESP at pH 8.2	4	15	27	33	20	18
Saturation extract:						
Moisture %			83	87	106	
pH-paste			7.1	7.1	7.8	
ECe (mS/cm)			7.0	9.0	4.0	

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	12.8
Mg "	8.0
K "	0.46
Na "	1.40
P (ppm)	32
Mn (me/100g)	0.68
Exch. acidity (me/100g)	
pH-H_2O (1:1 v/v)	6.1
C %	0.93
N %	0.26

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A11	3-8	6.0	0.3
	20	7.8	0.3
C1	40 (30-50)	7.4	0.4
	70	7.9	2.2
C2	70-90	7.4	4.5
	110	7.6	6.0
C3	130-140	7.8	5.5
	160	7.7	4.5
	280	7.8	1.4
	370	7.8	0.7
	420	7.6	0.6
groundwater		7.6	4.4

Profile description no. 5

Observation/date : P11, approx. 3 km south of Garsen-Witu road; 17/9/'81

Mapping unit : B1 I S2

Physiography : Floodplain; River basin land; approx. 200 m from the Lango La Simba

Topography : flat; weak gilgai microrelief

Vegetation : grasses and sedges, some palmtrees

Salinity/sodicity : slightly saline from 60 cm, moderately saline from 110 cm; sodic from 30 cm

Drainage conditions : imperfectly drained; seasonally flooded up to 0.5 m; groundwaterlevel at 160m

Profile description:

A_1 0-10 cm very dark gray (10 YR3/1); humic clay; moderate, very fine subangular blocky structure; very hard when dry, very firm when moist, sticky and very plastic when wet; abundant, fine roots; clear, smooth transition to

C_1 10-60 cm very dark gray (N3 moist); clay; strong, very coarse, prismatic and moderate, fine, angular blocky structure; very firm when moist, sticky and very plastic when wet; abundant, medium slickensides; common, fine roots; few (1%), fine (2 mm) manganese concretions; gradual, wavy transition to

C_2 60-110 cm dark grayish brown (10 YR4/2 moist); clay loam; moderate, fine angular blocky structure; very firm when moist, very sticky and very plastic when wet; common, medium slickensides; few (1%), fine (2mm) manganese concretions; few (2%), coarse (10 mm) carbonate concretions; salt crystals; slightly calcareous; diffuse, smooth transition to

C_3 110-180 cm dark grayish brown (10 YR4/2 moist); clay; weak, fine angular blocky structure; firm when moist, very sticky and very plastic when wet; abundant, thick slickensides; few (1%), fine (2 mm) manganese and few (1%), coarse (10 mm) carbonate concretions; slightly calcareous; type of transition not observed because of augering from 180 cm onwards

C_4 180-300 cm dark grayish brown (10 YR4/2 moist); clay; very firm when moist, sticky and very plastic when wet; common, fine, faint iron mottles; few (1%), small (1 mm) manganese and few (2%), coarse (2-10 mm) carbonate concretions; slightly calcareous

C_5 300-430 cm dark grayish brown (10 YR4/2 moist); sandy clay loam; firm when moist, sticky and plastic when wet; common, medium, distinct iron mottles; few (1%), fine (2 mm) manganese and few (1%), coarse (2-10 mm) carbonate concretions; many micas; slightly calcareous

C_6 430-450 cm sand; many micas

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 6

Observation no.: P7 Soil classification: vertic FLUVISOL

Mapping unit: B2 I SO

Horizon	A11	A12	C1	C2	C3	C4
Depth of sample (cm)	3-8	15-30	55-75	105-120	250-270	390-400
TEXTURE						
Sand % 2.0 - 0.05 mm	24	20	20	30	10	14
Silt % 0.05 - 0.002 mm	24	28	22	32	20	22
Clay % 0.002 - 0 mm	52	52	58	38	70	64
Texture class	C	C	C	CL	C	C
CHEMICAL DATA						
pH-H_2O (1:2.5 v/v)	6.1	7.5	8.0	7.5	7.3	7.9
pH-KCl "	5.1	5.9	6.6	6.8	6.2	6.8
EC (mS/cm) "	0.30	0.30	0.65	0.28	2.55	
$CaCO_3$ (%)						
$CaSO_4$ (%)	1.98	9.52	9.41	0.17	0.20	0.15
C (%)						
N (%)						
C/N						
CEC (me/100g), pH 8.2	48.9	44.6	38.4	31.5	55.6	48.9
Exch. Ca (me/100g)	18.0	16.8	19.2	28.0	22.0	26.0
" Mg "	12.0	12.7	17.5	15.2	22.5	24.7
" K "	2.0	1.2	1.0	0.6	1.0	0.7
" Na "	2.2	2.4	1.1	9.5	13.9	11.5
Sum of cations	34.2	33.1	38.8	53.3	59.4	62.9
Base sat. %, pH 8.2	70	74	>100	>100	>100	>100
ESP at pH 8.2	4	5	3	30	25	23
Saturation extract:						
Moisture %					170	94
pH-paste					7.0	7.5
ECe (mS/cm)					7.0	7.0

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	12.8
Mg "	8.8
K "	0.60
Na "	0.90
P (ppm)	38
Mn (me/100g)	0.54
Exch. acidity (me/100g)	-
pH-H_2O (1:1 v/v)	6.2
C %	1.02
N %	0.19

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A11	3-8	7.4	0.1
A12	20(15-30)	8.0	0.2
	40	8.0	0.3
	0	8.0	0.5
C1	55-75	7.9	0.7
	110	7.5	2.8
C2	105-120	7.7	3.1
	160	7.5	4.5
C3	250-270	7.2	3.6
C4	390-400	7.5	2.2
groundwater		7.3	9.0

Profile description no. 6

Observation/date	: P7; approx. 1.5 km north of road Garsen-Witu and : approx. 1.7 km east of Hewani-Wema track; 4/9/'81
Mapping unit	: B2 I SO
Physiography	: Floodplain, River basin land;
Topography	: flat; weak gilgai microrelief
Salinity/sodicity	: non-saline; sodic from 100 cm
Vegetation	: grasses
Drainage conditions	: imperfectly drained; seasonally flooded up to 0.5 m; groundwaterlevel at 2 m

Profile description:

A_{11}	0-10 cm	black (N2 moist); humic clay; weak, very fine angular and subangular blocky structure; very hard when dry, very firm when moist, sticky and plastic when wet; abundant, fine roots; clear, smooth transition to
A_{12}	10-35 cm	black (10 YR2/1 moist); humic clay; weak, coarse prismatic structure and strong, fine to very fine angular blocky structure; very hard when dry, very firm when moist, sticky and very plastic when wet; few (1%), fine (1 mm) manganese concretions; many, fine roots; gradual, wavy transition to
C_1	35-100 cm	very dark grayish brown (10 YR3/2 moist); clay; weak, coarse prismatic and moderate, fine to very fine angular blocky structure; very hard when dry, very firm when moist, sticky and very plastic when wet; few, medium slickensides; few (1%), fine (1 mm) manganese concretions; few, fine roots; clear, smooth transition to
C_2	100-180 cm	dark brown (10 YR3/3 moist); clay; massive structure; very hard when dry, very firm when moist, very sticky and very plastic when wet; few (1%), fine (1 mm) manganese concretions; small gypsum crystals and micas; slightly calcareous; type of transition not observed because of augering from 180 cm onwards
C_3	180-380 cm	dark grayish brown (10 YR4/2 moist); clay; sticky and very plastic when wet; few, medium, faint iron mottles; few (1%), fine (1 mm) manganese concretions
C_4	380-470 cm	brown to dark brown (10 YR4/3 moist); clay; sticky and very plastic when wet; common, medium, distinct iron mottles; few (1%), fine (1 mm) manganese concretions; slightly calcareous
C_5	470-490 cm	sand; many micas

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 7

Observation no.: P4 — Soil classification: vertic FLUVISOL, sodic phase

Mapping unit: B2 II S0

Horizon	A1	AC	C1	C2	C3
Depth of sample (cm)	0-5	10-25	65-80	130-140	190-205
TEXTURE					
Sand % 2.0 - 0.05 mm	24	18	22	28	40
Silt % 0.05 - 0.002 mm	20	8	10	10	16
Clay % 0.002 - 0 mm	56	74	68	62	44
Texture class	C	C	C	C	C
CHEMICAL DATA					
pH-H_2O (1:2.5 v/v)	6.2	6.8	7.2	6.7	7.5
pH-KCl "	5.3	5.6	6.0	6.0	6.3
EC (mS/cm) "	0.55	0.50	1.40	3.50	1.95
$CaCO_3$ (%)	0.16	0.16	0.15	0.11	0.20
$CaSO_4$ (%)	trace	tr.	tr.	1.47	tr.
C (%)	2.88	0.87	0.32	0.20	0.17
N (%)					
C/N					
CEC (me/100g), pH 8.2	48.5	48.9	55.6	43.4	36.0
Exch. Ca (me/100g)	29.0	14.0	28.0	32.0	14.4
" Mg "	12.5	9.8	21.5	19.5	16.6
" K "	2.4	1.1	1.3	0.7	0.7
" Na "	2.1	1.2	5.6	8.9	7.5
Sum of cations	46.0	26.1	56.4	61.1	39.2
Base sat. %, pH 8.2	95	53	>100	>100	>100
ESP at pH 8.2	4	2	10	20	21
Saturation extract:					
Moisture %			96	124	132
pH-paste			6.8	5.8	6.5
ECe (mS/cm)			2.0	11.0	6.0

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	17.6
Mg "	8.0
K "	0.72
Na "	0.98
P (ppm)	38
Mn (me/100g)	0.75
Exch. acidity (me/100g)	-
pH-H_2O (1:1 v/v)	6.2
C %	1.0
N %	0.19

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	0-5	6.1	0.3
C1	10-25	6.7	0.3
	20	6.9	0.3
	40	7.2	0.4
	70	7.2	1.0
C2	65-80	7.1	1.1
	110	6.5	3.9
C3	130-140	6.7	5.8
	160	7.3	5.0
	205	7.4	2.7
	250	7.5	2.5
groundwater		7.9	14

Profile description no. 7

Observation/date : P4; approx. 1.2 km south-east of Wema; 3/9'81

Mapping unit : B2 II SO

Physiography : Floodplain; River basin land; moderately low

Topography : flat; gilgai microrelief

Vegetation : grasses and some herbs

Salinity/sodicity : non-saline, moderately saline from 125 cm; sodic from 65 cm

Drainage conditions : imperfectly to poorly drained; seasonally flooded up to 0,90 cm; groundwaterlevel at 1.15 m

Profile description:

A_1 0-5 cm black (10 YR2/1 and N2 moist); humic clay; moderate, very fine subangular blocky structure; hard when dry, firm when moist, sticky and plastic when wet; clear, smooth transition to

AC 5-30 cm brown (7.5 YR4/2 moist); clay; moderate, very fine, angular blocky structure; firm when moist, sticky and very plastic when wet; common, fine, distinct iron mottles; few 1%), fine (2 mm) manganese concretions; many, fine roots, mainly along peds; gradual, wavy transition to

C_1 30-125 cm dark grayish brown (10 YR4/2 moist); clay; strong, fine to medium angular blocky structure; firm when moist, sticky and very plastic when wet; abundant, thick slickensides; few, fine, faint iron mottles; few (1%), fine (1 mm) manganese concretions; few, fine roots; gradual, smooth transition to

C_2 125-205 cm dark grayish brown (10 YR4/2 moist); clay; moderate, medium angular blocky structure; very stikcy and very plastic when wet; few, medium slickensides; few, medium, faint iron mottles; few (1%), fine (2 mm) manganese, concretions, few salt and gypsum crystals; type of transition not observed because of augering from 1 cm onwards

C_3 205-270 cm light olive brown (5Y5/6 moist); sand; single grain; slightly sticky and non plastic when wet; common, medium, distinct iron mottles; micas
End of augering due to sand flowing into the auger-hole

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 8

Observation no.: P9 — Soil classification: vertic FLUVISOL, sodic phase

Mapping unit: B2 II S0

Horizon	C1	A1b	C1b	C2b	C3b	C4b
Depth of sample (cm)	2-10	13-20	25-35	60-70	150-170	360-380
TEXTURE						
Sand % 2.0 - 0.05 mm	14	22	18	26	36	20
Silt % 0.05 - 0.002 mm	12	4	12	12	16	26
Clay % 0.002 - 0 mm	74	74	70	62	48	54
Texture class	C	C	C	C	C	C
CHEMICAL DATA						
pH-H_2O (1:2.5 v/v)	5.9	6.6	7.4	8.1	7.6	7.7
pH-KCl "	4.9	5.5	6.1	6.5	6.6	6.5
EC (mS/cm) "	0.9	0.55	0.60	0.65	2.25	1.35
$CaCO_3$ (%)	0.18	0.12	0.16	0.13	0.25	0.14
$CaSO_4$ (%)	trace	tr.	tr.	tr.	tr.	tr.
C (%)	1.28	1.31	0.55	0.20	0.15	0.29
N (%)						
C/N						
CEC (me/100g), pH 8.2	40.5	55.6	49.4	44.6	35.3	48.9
Exch. Ca (me/100g)	26.0	24.0	27.0	34.0	19.5	20.0
" Mg "	12.5	11.5	16.0	20.0	14.0	19.5
" K "	2.4	1.7	1.3	1.7	0.6	0.9
" Na "	1.4	1.6	2.8	4.9	8.1	9.4
Sum of cations	42.3	38.8	47.1	60.6	42.2	49.8
Base sat. %, pH 8.2	>100	70	95	>100	>100	>100
ESP at pH 8.2	3	3	6	11	23	19
Saturation extract:						
Moisture %	84				70	88
pH-paste	7.6				7.6	7.7
ECe (mS/cm)	1.10				5.5	3.0

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	16.4
Mg "	8.8
K "	0.86
Na "	0.78
P (ppm)	32
Mn (me/100g)	0.68
Exch. acidity (me/100g)	0.2
pH-H_2O (1:1 v/v)	5.3
C %	1.43
N %	0.25

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
C1	0-10	5.6	0.3
A1b	20(13-20)	6.4	0.2
	40	6.8	0.5
C2b	70	7.3	0.4
	110	7.4	0.7
C3b	160(150-170)	7.0	2.9
C4b	360-380	7.1	1.0
groundwater		7.0	8.0

Profile description no. 8

Observation date : P9; approx. 0.75 km south of Garsen-Witu road and 2.2 km west of Lango la Simba; 5/9/'81

Mapping unit : B2 II SO

Physiography : Floodplain; River basin land

Topography : flat; severe gilgai microrelief; some tussocks

Vegetation : grasses and sedges on tussocks; some doumpalms at about 50 meters distance

Salinity/sodicity : non-saline; sodic from 40 cm

Drainage conditions : poorly drained; seasonally flooded during relatively long periods, up to 1.00 m; groundwaterlevel at 0.75 m

Profile description:

C_1	0–10 cm	dark brown (7.5 YR3/2 moist); clay; weak, fine to very fine angular blocky structure; very hard when dry, very firm when moist, sticky and very plastic when wet; many, medium, prominent iron mottles; abrupt, smooth transition to
A_{1b}	10–24 cm	black (N2 moist); humic clay; moderate, very fine, subangular blocky structure; very firm when moist, sticky and very plastic when wet; few, fine, faint iron mottles; many, fine roots; clear, wavy transition to
C_{1b}	24–40 cm	very dark grayish brown (2.5 YR/2 moist); clay; moderate, very fine angular blocky structure; sticky and very plastic when wet; few, fine, faint iron mottles; few (1%), fine (1 mm) manganese concretions; few; fine roots, mainly along peds; diffuse, smooth transition to
C_{2b}	40–150 cm	dark grayish brown (2.5 Y4/2 moist); clay; moderate, fine angular blocky structure; sticky and very plastic when wet; abundant, thick slickensides; few, fine, faint iron mottles; few, fine roots extending to approximately 100 cm; type of transition not observed because of augering from 150 cm onwards
C_{3b}	150–280 cm	grayish brown (2.5 Y5/2 moist); clay; few, fine, faint iron mottles; sticky and very plastic when wet; few (1%), fine (2 mm) carbonate concretions; salt crystals, slightly calcareous
C_{4b}	280–400 cm	dark reddish brown (5 YR3/4); clay; very sticky and very plastic when wet; few (1%), fine (2 mm) manganese concretions

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 9

Observation no.: P21 — Soil classification: vertic FLUVISOL

Mapping unit: B2 II So

Horizon	A11	A12	AC	C1	C3g
Depth of sample (cm)	0-8	20-40	60/80-90	90-120	240-260
TEXTURE					
Sand % 2.0 - 0.05 mm	24	18	16	20	18
Silt % 0.05 - 0.002 mm	20	22	24	26	14
Clay % 0.002 - 0 mm	56	60	60	54	68
Texture class	C	C	C	C	C
CHEMICAL DATA					
$pH-H_2O$ (1:2.5 v/v)	6.0	7.0	7.1	7.2	6.5
pH-KCl "	4.7	5.5	6.2	6.4	5.5
EC (mS/cm) "	0.25	0.40	2.90	2.85	2.40
$CaCO_3$ (%)					
$CaSO_4$ (%)					
C (%)	2.66				
N (%)					
C/N					
CEC (me/100g), pH 8.2	48.6	41.2	46.6	26.1	41.2
Exch. Ca (me/100g)	10.1	16.5	8.2	26.7	13.2
" Mg "	7.7	11.5	8.2	9.5	14.1
" K "	1.31	0.36	0.20	trace	0.36
" Na "	0.32	0.80	1.54	3.98	4.22
Sum of cations	19.43	29.16	18.14	40.18	31.88
Base sat. %, pH 8.2	40	71	39	>100	77
ESP at pH 8.2	<1	2	3	15	10
Saturation extract:					
Moisture %			92.1	66.2	104.6
pH-paste			7.1	7.2	6.6
ECe (mS/cm)			9.0	8.0	6.0

FERTILITY ASPECTS: (depth in cm)	0-8	0-20
Ca (me/100 g)	15.4	14.0
Mg "	0.6	9.2
K "	0.63	0.28
Na "	0.81	1.12
P (ppm)	31	24
Mn (me/100g)	0.35	0.40
Exch. acidity (me/100g)		
$pH-H_2O$ (1:1 v/v)	5.9	5.9
C %	2.66	0.19
N %	0.37	1.12

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A11	5	5.5	0.60
A12	15	5.8	0.54
A13	40	6.8	0.80
AC	70	7.2	0.44
C1	110	7.1	6.0
C2g	170	6.9	5.0
C3g	240	6.6	3.9
C4g	320	6.8	1.6
gr.w.	380	6.5	1.1

Profile description no. 9

Observation date : P21; approx. 3 km south of Moa; 28/3/'81

Mapping unit : B2 II SO

Physiography : Floodplains; River basin land, in the vicinity of River levee land

Topography : flat; moderate gilgai microrelief

Vegetation : grasses and reeds; some doumpalms at about 50 meters distance

Salinity/sodicity : non-saline to 60 cm, slightly saline from 60 cm onwards; sodic from 90 cm

Drainage conditions : imperfectly to poorly drained; seasonally flooded up to 1 m; groundwaterlevel at 3.80 m

Profile description:

A_{11}	0-8 cm	black (N2 moist); humic clay; strong, very fine angular blocky structure; firm when moist, sticky and plastic when wet; abundant fine roots; clear, smooth transition to
A_{12}	8-30 cm	black (N2 moist); humic clay; strong, very fine and fine angular blocky structure; firm when moist, sticky and very plastic when wet; common, fine roots; clear, wavy transition to
A_{13}	30-60 cm	very dark gray (10 YR3/1 moist); clay; moderate, very fine, angular blocky structure; few, medium slickensides; very firm when moist, sticky and very plastic when wet; common, fine, faint iron mottles, decreasing with depth to few; fine roots along peds; gradual, wavy transition to
AC	60-90 cm	very dark gray (10 YR3/1 moist); clay: weak, medium prismatic structure, breaking into moderate, fine, angular blocks; abundant thick slickensides; very firm when moist, very sticky and very plastic when wet; few, fine, faint iron mottles; few fine roots, gradual, wavy transition to
C_1	90-140 cm	dark gray (10 YR4/2 moist); clay with very thin layers of sand; moderate, fine, angular blocky structure; very firm when moist, sticky and plastic when wet; common, fine distinct iron mottles; common (5%), medium to coarse (2-10 mm) carbonate concretions; few micas; very fine roots along peds; clear, wavy transition to
C_2g	140-200 cm	dark gray (10 YR4/2 moist); clay; very firm when moist, very sticky and very plastic when wet; common, medium, distinct iron mottles; salt crystals and micas
C_3g	200-300 cm	very dark gray (5Y 3/1 moist); clay; consistency as above; common, medium, distinct iron mottles; salt crystals
C_4g	300-380 cm	very dark gray (5Y 3/1 moist); sandy clay; consistency as above; prominent iron mottles

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 10

Observation no.: P19 Soil classification: vertic FLUVISOL

Mapping unit: B/L 2 II So

Horizon	A11	A12	C1	C2	C3
Depth of sample (cm)	2-8	13-23	30-50	80-100	155-165
TEXTURE					
Sand % 2.0 - 0.05 mm	26	14	22	38	64
Silt % 0.05 - 0.002 mm	24	12	18	18	16
Clay % 0.002 - 0 mm	50	74	60	44	20
Texture class	C	C	C	C	SCL
CHEMICAL DATA					
pH-H_2O (1:2.5 v/v)	5.6	6.9	7.8	8.4	7.7
pH-KCl "	4.6	5.4	5.8	6.9	6.9
EC (mS/cm) "	0.40	0.40	0.30	0.65	0.95
$CaCO_3$ (%)	0.20	0.10	0.10	1.39	0.09
$CaSO_4$ (%)	trace	tr.	0.10	tr.	tr.
C (%)					
N (%)					
C/N					
CEC (me/100g), pH 8.2	48.9	58.4	48.4	35.8	16.3
Exch. Ca (me/100g)	15.0	27.0	18.4	18.0	7.2
" Mg "	10.0	19.5	14.8	17.3	1.8
" K "	1.7	1.6	1.6	0.9	0.4
" Na "	0.8	2.8	2.7	4.8	2.6
Sum of cations	27.5	50.9	37.5	41.0	12.0
Base sat. %, pH 8.2	56	87	77	>100	>100
ESP at pH 8.2	2	5	5	13	16
Saturation extract:					
Moisture %					30
pH-paste					7.1
ECe (mS/cm)					6.0

FERTILITY ASPECTS: (depth in cm)	
Ca (me/100 g)	
Mg "	
K "	
Na "	
P (ppm)	
Mn (me/100g)	
Exch. acidity (me/100g)	
pH-H_2O (1:1 v/v)	
C %	
N %	

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A11	2-8	5.0	0.2
A12	12-23	6.5	0.2
	20	7.3	0.2
C1	30-50	7.9	0.2
	40	7.7	0.3
	70	8.5	0.6
C2	80-100	8.5	0.8
	110	8.5	0.9
C3	155-165	7.9	2.0
	160	8.0	2.6
groundwater		7.0	0.8

Profile description no. 10

Observation/date	: P19; approx. 6 km south-west of Moa; 24/9/'81
Mapping unit	: $\frac{B^2}{L}$ II SO
Physiography	: Floodplain; River basin land
Topography	: flat; weak gilgai microrelief
Vegetation	: grasses
Salinity/sodicity	: non-saline ; sodic from 80 cm
Drainage conditions	: imperfectly drained; seasonally flooded up to 0.6 m groundwaterlevel at 2.50 m

Profile description:

A_{11}	0-10	cm	black (N2 moist); humic clay; moderate, very fine subangular blocky structure; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet, common, fine roots; many, medium, prominent iron mottles; clear, wavy transition to
A_{12}	10-25	cm	black (N2 moist); humic clay; strong, coarse prismatics and moderate, fine to very fine angular blocky structure; common, medium slickensides; very hard when dry, very firm when moist, sticky and very plastic when wet; gradual, wavy transition to
C_1	25-65	cm	dark grayish brown (10 YR4/2 moist); clay; weak, coarse prismatics and moderate, fine to very fine angular blocky structure; common, thick slickensides; very hard when dry,very firm when moist, sticky and very plastic when wet; few, fine, faint iron mottles; few (1%), fine (1 mm) manganese concretions; abrupt, smooth transition to
C_2	65-150	cm	dark grayish brown (10 YR4/2 moist); clay; weak, coarse, angular blocky structure;common, thick slickensides; very hard when dry, very firm when moist, sticky and very plastic when wet; common, fine, distinct iron mottles; few (1%), fine (1 mm) and many (5%) medium to coarse (2-10 mm) carbonate concretions; many micas; calcareous; augering from 150 cm onwards
C_3	150-250	cm	yellowish brown (10 YR5/4 moist) and gray (5Y5/1 moist); sandy clay loam; hard when dry, friable when moist, non sticky and non plastic when wet; few, medium, faint iron mottles; many micas
C_4	250-300	cm	greenish gray (5GY5/1 moist); fine sand; many micas; end of augering due to sand flowing into the auger-hole

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 11

Observation no.: P17 Soil classification: vertic FLUVISOL, sodic phase

Mapping unit: B2 II So / T

Horizon	A11	A12	C1	C2	C3	C4
Depth of sample (cm)	5-10	15-20	60-70	100-120	150-160	260-270
TEXTURE						
Sand % 2.0 - 0.05 mm	24	38	34	38	28	28
Silt % 0.05 - 0.002 mm	16	12	10	8	10	24
Clay % 0.002 - 0 mm	60	50	56	54	62	48
Texture class	C	C	C	C	C	C
CHEMICAL DATA						
pH-H_2O (1:2.5 v/v)	5.3	6.8	8.0	8.0	8.2	8.4
pH-KCl "	4.1	5.5	6.3	6.7	6.9	6.7
EC (mS/cm) "	0.45	0.45	0.35	2.25	2.30	0.70
$CaCO_3$ (%)						
$CaSO_4$ (%)						
C (%)	1.89	0.79	0.52	0.12	0.23	0.09
N (%)						
C/N						
CEC (me/100g), pH 8.2	58.1	37.4	38.2	34.6	51.1	35.8
Exch. Ca (me/100g)	16.5	14.5	12.8	10.7	13.7	6.1
" Mg "	6.5	7.3	10.9	9.5	13.7	16.1
" K "	1.0	0.4	0.4	0.3	0.2	0.1
" Na "	1.4	3.1	4.0	3.9	6.7	13.0
Sum of cations	25.4	25.2	28.1	24.4	34.3	35.2
Base sat. %, pH 8.2	44	67	74	70	67	98
ESP at pH 8.2	3	8	11	11	13	36
Saturation extract:						
Moisture %					68.7	32.2
pH-paste						
ECe (mS/cm)					4.0	12.5

FERTILITY ASPECTS: (depth in cm)	0-10	5-10
Ca (me/100 g)	17.6	14.7
Mg "	6.9	5.9
K "	0.7	0.5
Na "	1.6	1.0
P (ppm)	21	19
Mn (me/100g)	0.25	0.28
Exch. acidity (me/100g)		0.1
pH-H_2O (1:1 v/v)	5.7	5.3
C %	1.81	1.89
N %	0.38	0.39

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A11	10	5.6	0.6
A12	20	6.5	0.6
C1	70	7.9	1.0
C1	70 (repl.)	8.0	1.5
C2	100	7.0	6.0
C3	160	7.8	3.7
C4	270	8.1	1.7
groundwater		7.3	1.6

Profile description no. 11

Observation/date :P17; 28/3/'81

Mapping unit :$\frac{B2}{T}$ II SO

Physiography :Floodplain; River basin land

Topography :flat; gilgai microrelief; cracks

Vegetation :grasses, some reeds

Salinity/sodicity :non-saline; sodic from 25 cm

Drainage conditions :imperfectly to poorly drained; seasonally flooded up to 0.6 m groundwaterlevel at 4.10 m

Profile description:

A_{11}	0-10 cm	black (10 YR2/1 moist); humic clay; strong, fine angular blocky structure; very hard when dry, firm when moist, sticky and very plastic when wet; few, fine, distinct iron mottles; common, fine roots; clear, smooth transition to
A_{12}	10-25 cm	very dark gray (N3 moist); clay; strong, coarse angular blocky structure; common, thin slickensides; very firm when moist, very sticky and very plastic when wet; few, fine, faint iron mottles; very few (less than (1%), fine (2 mm) carbonate concretions; common, very fine roots; clear, wavy transition to
C_1	25-95 cm	black (5Y 2/1 moist); clay; strong, coarse prismatic structure, up to 70 cm breaking into strong, coarse angular blocks, below 70 cm into moderate, coarse, angular blocks; abundant, thick slickensides; very hard when dry, very firm when moist, very sticky and very plastic when wet; few, very fine and fine roots along peds; gradual, wavy transition to
C_2	95-140 cm	dark gray (N4 moist); clay; structure not observed, too wet; very firm when moist, very sticky and very plastic when wet; common, thick slickensides; few, coarse, faint iron mottles; common (3%), medium (1-10mm) carbonate concretions; gradual, smooth transition to
C_3	140-210 cm	grayish brown (2.5 Y5/2 moist); clay; structure not observed, too wet; few, thin slickensides; firm when moist, sticky and plastic when wet; common, medium, faint iron mottles; common (3%), coarse(10-20mm) carbonate concretions; slightly calcareous; clear, smooth transition to
C_4	210-400 cm	brown (10 YR5/3 moist); clay; firm when moist, slightly sticky and slightly plastic when wet; many, fine, faint iron mottles; micas
C_5	400-420 cm	pale olive (5 Y6/3 moist); loamy sand; micas and black grains End of augering due to sand flowing into the auger hole

Remarks: -the fill-up topsoil material in the cracks was very wet and sticky, the prismas were still dry and hard

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 12

Observation no.: P13 Soil classification: vertic FLUVISOL, sodic phase
Mapping unit: B3 I So

Horizon	A11	A12	C1	C1	C1	C2
Depth of sample (cm)	2-5	25-35	75-90	105-120	160-200	280-310
TEXTURE						
Sand % 2.0 - 0.05 mm	20	16	20	18	20	66
Silt % 0.05 - 0.002 mm	22	18	10	12	12	6
Clay % 0.002 - 0 mm	58	66	70	70	68	28
Texture class	C	C	C	C	C	SCL
CHEMICAL DATA						
pH-H_2O (1:2.5 v/v)	5.8	7.6	8.1	7.6	7.7	8.4
pH-KCl "	4.9	6.1	6.8	6.8	6.9	6.8
EC (mS/cm) "	0.55	0.45	1.20	2.55	2.00	0.45
$CaCO_3$ (%)	0.16	0.12	0.44	0.55	0.09	0.13
$CaSO_4$ (%)						
C (%)	2.10	0.58	0.38	0.20	0.23	0.20
N (%)						
C/N						
CEC (me/100g), pH 8.2	58.3	62.3	55.6	48.9	55.6	20.8
Exch. Ca (me/100g)	30.0	31.0	28.0	29.0	6.4	18.0
" Mg "	14.0	20.0	20.5	20.5	19.5	8.5
" K "	1.5	1.1	0.9	0.8	0.7	0.3
" Na "	1.7	3.8	10.2	14.9	13.4	2.4
Sum of cations	47.2	55.9	59.6	65.2	40.0	29.2
Base sat. %, pH 8.2	81	90	>100	>100	72	>100
ESP at pH 8.2	3	5	18	30	24	11
Saturation extract:						
Moisture %			127	98	107	
pH-paste			7.8	7.8	8.2	
ECe (mS/cm)			1.05	5.00	5.00	

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	19.2
Mg "	9.2
K "	0.58
Na "	0.92
P (ppm)	30
Mn (me/100g)	0.52
Exch. acidity (me/100g)	0.1
pH-H_2O (1:1 v/v)	5.4
C %	1.49
N %	0.20

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A11	2-5	5.4	0.2
	20	7.0	0.2
A12	25-35	7.7	0.2
	40	8.2	0.2
	70	8.4	0.7
C1	75-90	8.8	0.6
C1	110 (105-120)	7.5	5.0
	160	7.8	2.2
C1	180 (160-200)	7.7	3.0
C2	300 (280-310)	7.3	0.4
	330	8.3	0.4
groundwater		8.0	2.3

Profile description no. 12

Observation/date	: P13; approx. 1.5 km north-east of Galili, 26/9/'81
Mapping unit	: B3 I SO
Physiography	: Floodplain, River basin land
Topography	: flat; moderate gilgai microrelief
Vegetation	: sedges, some small bushes
Salinity/sodicity	: non-saline to 90 cm, slightly saline from 90 cm onwards; sodic from 60 cm
Drainage conditions	: poorly drained, seasonally flooded up to 1.00 m:ground-waterlevel at 2.50 m

Profile description:

A_{11}	0-7 cm	black (10 YR2/1 moist); humic clay; strong, very fine, subangular blocky structure; slightly hard when dry, firm when moist, sticky and slightly plastic when wet; few, faint iron mottles along roots; clear, smooth transition to
A_{12}	7-60 cm	black (N2 moist); clay; moderate, very coarse prismatic structure, breaking into weak, fine to very fine angular blocky structure; common, medium slickensides; very hard when dry, very firm when moist, sticky and very plastic when wet; from 120 cm onwards few, fine, faint iron mottles; from 70-100 cm, few (1%), coarse (5-10 mm) carbonate concretions; common, fine roots; clear, smooth transition to
C_1	60-260 cm	dark grayish brown (10 YR4/2 moist) and gray (5Y5/1 moist); clay; sticky and very plastic when wet; common, medium, faint iron mottles; slightly calcareous; type of transition not observed because of augering from 170 cm onwards
C_2	260-360 cm	pale brown (10 YR6/3 moist); sandy clay loam; slightly hard when dry, sticky and non plastic when wet; common, medium, faint iron mottles; slightly calcareous. End of augering because of sand flowing into auger hole

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 13

Observation no.: P14 — Soil classification: vertic FLUVISOL

Mapping unit: B3 I So

Horizon	A1	C1	C2
Depth of sample (cm)	0-10	20-25	70-80
TEXTURE			
Sand % 2.0 - 0.05 mm	20	20	16
Silt % 0.05 - 0.002 mm	16	14	8
Clay % 0.002 - 0 mm	64	66	76
Texture class	C	C	C
CHEMICAL DATA			
pH-H_2O (1:2.5 v/v)	6.5	7.1	8.2
pH-KCl "	5.1	5.5	6.6
EC (mS/cm) "	0.50	0.45	0.75
$CaCO_3$ (%)	0.31	0.13	0.07
$CaSO_4$ (%)	trace	tr.	tr.
C (%)	2.42	0.70	0.38
N (%)			
C/N			
CEC (me/100g), pH 8.2	55.6	51.6	58.4
Exch. Ca (me/100g)	15.0	19.6	32.0
" Mg "	19.5	7.3	19.5
" K "	1.8	1.2	0.8
" Na "	0.9	3.1	3.4
Sum of cations	37.2	31.2	55.7
Base sat. %, pH 8.2	67	60	95
ESP at pH 8.2	2	6	6
Saturation extract:			
Moisture %			
pH-paste			
ECe (mS/cm)			

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	18.2
Mg "	9.2
K "	0.60
Na "	1.30
P (ppm)	32
Mn (me/100g)	0.32
Exch. acidity (me/100g)	
pH-H_2O (1:1 v/v)	5.7
C %	1.17
N %	0.24

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	0-10	5.7	0.2
C1	10-33	7.2	0.3
	20	7.1	0.2
C2	33-160	8.3	0.8
	40	7.9	0.2
	70	8.1	0.5
	110	8.1	1.7
	160	8.0	3.7
C3	170	8.0	3.9
	200	8.2	3.5
C4	400	8.2	1.7

Profile description no. 13

Observation/date	: P14; approx. 4 km due east of Galili; 9/9/'81
Mapping unit	: B3 I SO
Physiographic	: Floodplain; River basin land
Topography	: flat; gilgai microrelief
Vegetation	: sedges on tussocks
Salinity/sodicity	: non-saline ; non-sodic
Drainage condition	: poorly drained, seasonally flooded up to 1.50 m

Profile description:

A_1	0-10 cm	black (N2 moist); humic clay; moderate, very fine, subangular blocky structure; firm when moist, sticky and plastic when wet; many fine roots; clear, wavy transition to
C_1	10-33 cm	very dark gray (10 YR3/1 moist); humic clay; moderate, very fine, angular blocky structure; firm when moist, sticky and very plastic when wet; common, fine roots; few (1%), fine (1 mm) manganese concretions; diffuse, wavy transition to
C_2	33-160 cm	dark gray (10 YR4/1 moist); clay; moderate, fine, angular blocky structure; abundant, medium slickensides; firm when moist, sticky and very plastic when wet; few, very fine, faint iron mottles; few (1%), fine (1 mm) manganese concretions, few (1%), fine (2 mm) carbonate concretions; few, decreasing to very few, fine roots along peds up to a depth of 80 cm; type of transition not observed because of augering from 160 cm onwards
C_3	160-250 cm	gray (10 YR5/1 moist); clay; very firm when moist, sticky and very plastic when wet; common, fine, faint iron mottles; few (1%), fine (2 mm) manganese and carbonate concretions; few micas
C_4	250-460 cm	grayish brown (10 YR5/2 moist); clay; very firm when moist, sticky and very plastic when wet; few, fine, faint iron mottles; few (2%), medium (3 mm) carbonate and manganese concretions; few micas

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 14

Observation no.: P16 Soil classification: vertic FLUVISOL, sodic phase

Mapping unit: B3 I So

Horizon	A1	C1	A1b	C1b	C2b	C3b	C4b
Depth of sample (cm)	2-8	15-25	36-44	60-80	110-130	210-250	350-400
TEXTURE							
Sand % 2.0 - 0.05 mm	22	12	24	18	20	14	30
Silt % 0.05 - 0.002 mm	24	12	16	16	30	24	18
Clay % 0.002 - 0 mm	54	76	60	66	50	62	52
Texture class	C	C	C	C	C	C	C
CHEMICAL DATA							
pH-H_2O (1:2.5 v/v)	6.2	7.1	7.1	7.6	7.5	7.1	7.2
pH-KCl "	5.4	5.8	6.7	6.1	6.5	6.4	6.4
EC (mS/cm) "	0.70	0.50	0.50	0.60	1.75	3.50	2.65
$CaCO_3$ (%)	0.10	0.13	0.12	0.14	0.24	0.13	0.10
$CaSO_4$ (%)	tace	tr.	0.14	tr.	tr.	tr.	tr.
C (%)	2.59	0.70	0,99	0.64	0.23	0.26	0.17
N (%)							
C/N							
CEC (me/100g), pH 8.2	41.5	40.4	44.6	40.4	44.5	41.4	37.4
Exch. Ca (me/100g)	18.6	19.2	20.0	20.0	24.0	24.0	20.0
" Mg "	7.9	10.0	9.5	11.7	14.5	17.5	16.7
" K "	2.0	0.8	0.6	0.8	0.7	0.9	0.8
" Na "	0.3	1.6	2.1	4.7	7.1	9.4	8.6
Sum of cations	28.8	31.6	32.2	37.2	46.3	51.7	46.1
Base sat. %, pH 8.2	69	78	72	92	>100	>100	>100
ESP at pH 8.2	1	4	5	12	16	23	23
Saturation extract:							
Moisture %					68	89	78.
pH-paste					7.6	7.3	7.3
ECe (mS/cm)					4.50	9.00	8.00

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	18.8
Mg "	9.6
K "	0.74
Na "	0.84
P (ppm)	32
Mn (me/100g)	0,48
Exch. acidity (me/100g)	0.1
pH-H_2O (1:1 v/v)	5.4
C %	2.16
N %	0,25

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	2-8	6.4	0.1
C1	20(15-25)	6.7	0.2
A1b	40(36-44)	7.0	0.3
C1b	70(60-80)	7.4	0.5
	110	7.4	1.3
C2b	110-130	7.5	1.9
	160	7.0	4.4
C3b	210-250	7.1	6.0
C4b	350-400	7.1	5.6
groundwater		6.7	24

Profile description no. 14

Observation/date	: P16; approx. 3 km south of Galili;26/9/'81
Mapping unit	: B3 I SO
Physiography	: Floodplain; River basin land
Topography	: flat; moderate gilgai microrelief
Vegetation	: grasses and sedges
Salinity/sodicity	: non-saline; sodic from 45 cm
Drainage conditions	: poorly drained; seasonally flooded up to 1.00 m; groundwaterlevel at 1.50 m

Profile description:

A_1	0-10	cm	black (10 YR2/1 moist); humic clay; moderate, very fine, subangular blocky structure; hard when dry, firm when moist, sticky and plastic when wet; few, fine, faint iron mottles along roots; few, fine roots; clear, wavy transition to
C_1	10-35	cm	olive gray (5Y4/2 moist); clay; moderate, very fine angular blocky structure; few, thin slickensides; very firm when moist, sticky and very plastic when wet; few, fine, iron mottles; few, fine roots; abrupt, wavy transition to
A_{1b}	35-45	cm	very dark gray (N3 moist); clay; weak, very fine angular blocky structure;common, thin slickensides; sticky and very plastic when wet; few,fine roots; clear, wavy transition to
C_{1b}	45-105	cm	very dark grayish brown (2.5 Y3/1 moist); clay; moderate, medium angular blocky structure; common, thick slickensides; sticky and very plastic when wet; few, fine, faint iron mottles; few (1%), fine (1 mm) manganese concretions; few, fine roots; diffuse, smooth transition to
C_{2b}	105-180	cm	dark brown (10 YR3/3 moist); clay; weak, medium to fine angular blocky structure; common, thick slickensides; sticky and very plastic when wet; few (1%), fine (1 mm) manganese concretions; type of transition not observed because of augering from 180 cm onwards
C_{3b}	180-500	cm	dark grayish brown (10 YR4/2 moist); clay; sticky and very plastic when wet; common, medium distinct iron mottles; few (1%), fine (1 mm) manganese concretions; few micas
C_{4b}	500-550	cm	dark greenish gray (5G4/1 moist), clay

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 15

Observation no.: P20 — Soil classification: vertic FLUVISOL, sodic phase

Mapping unit: B3 I SO

Horizon	A1	C1	C2	A1b	C1b
Depth of sample (cm)	5-15	30-40	70-80	100-110	140-150
TEXTURE					
Sand % 2.0 - 0.05 mm	48	48	30	38	30
Silt % 0.05 - 0.002 mm	22	32	22	22	20
Clay % 0.002 - 0 mm	30	20	48	40	50
Texture class	CL	L	C	C	C
CHEMICAL DATA					
$pH-H_2O$ (1:2.5 v/v)	7.4	7.7	8.0	7.2	8.0
pH-KCl "	6.3	6.2	6.4	6.4	6.7
EC (mS/cm) "	0.20	0.10	0.40	0.45	1.15
$CaCO_3$ (%)	0.17	0.19	0.21	1.15	0.32
$CaSO_4$ (%)	0.12	trace	tr.	tr.	tr.
C (%)	1.02	0.26	0.29	0.26	0.17
N (%)					
C/N					
CEC (me/100g), pH 8.2	22.0	16.4	39.0	34.6	39.0
Exch. Ca (me/100g)	11.6	5.6	14.7	8.0	9.0
" Mg "	16.5	5.8	3.8	6.5	1.3
" K "	0.9	0.4	0.9	0.5	0.7
" Na "	0.7	0.4	3.1	1.9	1.7
Sum of cations	29.7	13.2	22.5	16.9	12.7
Base sat. %, pH 8.2	>100	80	58	49	33
ESP at pH 8.2	3	2	8	6	4
Saturation extract:					
Moisture %					75
pH-paste					8.2
ECe (mS/cm)					2.15

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	14.2
Mg "	5.0
K "	0.68
Na "	0.54
P (ppm)	40
Mn (me/100g)	0.26
Exch. acidity (me/100g)	
$pH-H_2O$ (1:1 v/v)	6.0
C %	1.75
N %	0.25

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	5-15	7.4	0.1
	20	7.7	0.3
C1	30-40	7.4	0.1
	40	7.2	0.1
	70	7.4	0.2
C2	70-80	7.7	0.1
A1b	110	8.0	0.2
C3b	140-150	8.1	0.3
	160	7.9	0.3
	280	7.5	1.3
	450	6.5	2.4
groundwater		6.6	8.0

Profile description no. 15

Observation/date	: P20; approx. 7.5 km south-west of Moa; 4/10/'81
Mapping unit	: B3 I SO
Physiography	: Floodplain, River basin land; approx. 500 m south of Abarfarda course
Topography	: flat; moderate gilgai microrelief
Vegetation	: grasses
Salinity/sodicity	: non-saline ; non-sodic to 60 cm, sodic onwards
Drainage conditions	: poorly drained; seasonally flooded up to 0.6 m

Profile decsription

A_1	0-20 cm	black (N2 moist); humic clay loam; weak, fine, subangular and angular blocky structure; firm when moist, sticky and plastic when wet; micas; abrupt, wavy transition to
C_1	20-60 cm	dark brown (10 YR4/3 moist); loam; weak,very fine, subangular and angular blocky structure; friable when moist, sticky and slightly plastic when wet; few, fine, faint iron mottles; micas; abrupt wavy transition to
C_2	60-90 cm	dark grayish brown (10 YR4/2 moist); clay; moderate, fine, angular blocky structure; abundant, thick slickensides; very sticky and plastic when wet; common, fine, distinct iron mottles; micas; clear, wavy transition to
A_{1b}	90-120 cm	very dark gray (10 YR3/1 moist); clay; moderate, fine, subangular and angular blocky structure; common, medium slickensides; firm when moist, sticky and plastic when wet; few, fine iron mottles; few (1%), fine (1 mm) carbonate and manganese concretions; clear, wavy transition to
C_{1b}	120-170 cm	dark grayish brown (10 YR4/2 moist); clay; weak, fine, subangular blocky structure; few, thin slickensides; firm when moist, sticky and very plastic when wet; few, fine, faint iron mottles; slightly calcareous; few (1%), fine (1 mm) carbonate concretions; micas; type of transition not observed because of augering from 170 cm onwards
C_{2b}	170-270 cm	dark grayish brown (10 YR4/2 moist); clay; firm when moist, sticky and very plastic when wet; few, fine, faint iron mottles; slightly calcareous; few (1%), fine (1 mm) carbonate concretions; micas
C_{3b}	270-300 cm	dark grayish brown (10 YR4/2 moist); sandy clay loam; firm when moist, sticky and very plastic when wet; many, medium, prominent iron mottles; micas
C_{4b}	300-500 cm	grayish brown (2.5 Y5/2); clay; firm when moist, very sticky and plastic when wet; common, fine, distinct iron mottles

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 16

Observation no.: P2 Soil classification: vertic FLUVISOL

Mapping unit: B3 II So

Horizon	A1	C1	C2	C3
Depth of sample (cm)	7-12	20-30	90-120	155-175
TEXTURE				
Sand % 2.0 - 0.05 mm	16	18	16	48
Silt % 0.05 - 0.002 mm	16	12	14	18
Clay % 0.002 - 0 mm	68	70	70	34
Texture class	C	C	C	SCL
CHEMICAL DATA				
pH-H_2O (1:2.5 v/v)	6.9	6.2	6.6	7.2
pH-KCl "	5.5	5.2	5.3	6.1
EC (mS/cm) "	0.45	0.75	2.05	0.29
$CaCO_3$ (%)	0.19	0.12	0.17	0.13
$CaSO_4$ (%)	trace	tr.	tr.	tr.
C (%)				
N (%)				
C/N				
CEC (me/100g), pH 8.2	51.9	44.6	39.5	26.9
Exch. Ca (me/100g)	28.0	18.0	22.0	11.2
" Mg "	12.7	11.0	19.5	12.8
" K "	1.6	0.6	0.8	0.4
" Na "	1.2	0.9	4.5	4.7
Sum of cations	43.5	30.5	46.8	29.1
Base sat. %, pH 8.2	84	68	>100	>100
ESP at pH 8.2	2	2	14	18
Saturation extract:				
Moisture %			97.1	
pH-paste			8.0	
ECe (mS/cm)			1.30	

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	19.6
Mg "	7.6
K "	0.66
Na "	0.60
P (ppm)	30
Mn (me/100g)	0.75
Exch. acidity (me/100g)	
pH-H_2O (1:1 v/v)	5.7
C %	1.86
N %	0.22

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	10(7-12)	6.9	
C1	20	7.1	no reliable
	40	7.6	data due
	70	7.2	to failure
C2	100(90-120)	6.7	EC-meter
	110	6.6	
	160(155-175)	6.7	
	280	7.6	
	340	7.6	
	400	7.2	

Profile description no. 16

Observation/date : P2; approx. 0.5 km west of Vumbwe village; 7/10/'81
Mapping unit : B3 II SO
Physiography : Floodplain; River basin land
Topography : flat, weak gilgai microrelief
Vegetation : sedges
Salinity/sodicity : non-saline ; sodic from 90 cm
Drainage conditions : poorly drained, seasonally flooded up to 1.00 m

Profile description:

A_1	0-15 cm	very dark brown (10 YR2/2 moist); humic clay; moderate, fine subangular and angular blocky structure; hard when dry, firm when moist, sticky and plastic when wet; common, fine, faint iron mottles; few (1%), fine (2 mm) manganese concretions; common, fine roots; gradual, wavy transition to
C_1	15-35 cm	dark brown (%5YR3/2 moist); clay; medium angular blocky structure; few, thin slickensides; firm when moist, sticky and plastic when wet; many, fine, faint iron mottles; few (1%), fine (2 mm) manganese concretions; few, fine roots; gradual, wavy transition to
C_2	35-140 cm	dark grayish brown (10 YR4/2 moist); clay; weak, moderate angular blocky structure; common, medium slickensides; firm when moist, sticky and plastic when wet; common, fine, faint iron mottles; few, fine roots; gradual, wavy transition to
C_3	140-220 cm	brown (10 YR5/3 moist); sandy clay loam; weak, medium subangular blocky structure; friable when moist, slightly sticky and slightly plastic when wet; few, fine, distinct iron mottles; micas; type of transition not observed because of augering from 200 cm onwards
C_4	220-320 cm	dark grayish brown (10 YR4/2 moist); clay; firm when moist, sticky and plastic when wet; few, fine, faint iron mottles; few (1%), fine (1-2 mm) manganese and carbonate concretions
C_5	320-370 cm	grayish brown (10 YR5/2 moist); sandy clay loam, slightly sticky and slightly plastic when wet; few, fine, distinct iron mottles; micas
C_6	370-460 cm	grayish brown (10 YR5/2 moist); clay; slightly sticky and slightly plastic when wet; few, fine, faint iron mottles; micas

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 17

Observation no.: P6 — Soil classification: vertic FLUVISOL

Mapping unit: B3 II So

Horizon	A1	C1	C1	C2	C3
Depth of sample (cm)	4-10	15-25	50-70	110-130	160-170
TEXTURE					
Sand % 2.0 - 0.05 mm	30	22	26	20	42
Silt % 0.05 - 0.002 mm	10	14	6	20	18
Clay % 0.002 - 0 mm	60	64	68	60	40
Texture class	C	C	C	C	C/SC
CHEMICAL DATA					
$pH-H_2O$ (1:2.5 v/v)	6.6	7.4	7.4	7.7	7.9
pH-KCl "	5.5	6.0	5.9	6.0	6.3
EC (mS/cm) "	0.45	0.50	0.40	0.40	0.40
$CaCO_3$ (%)	0.19	0.15	0.15	0.11	0.08
$CaSO_4$ (%)	trace	tr.	tr.	tr.	tr.
C (%)	1.91	0.61	0.26	0.29	0.26
N (%)					
C/N					
CEC (me/100g), pH 8.2	55.6	48.9	51.6	40.7	34.2
Exch. Ca (me/100g)	19.0	25.2	24.0	14.5	18.0
" Mg "	7.9	3.3	16.0	11.7	11.0
" K "	1.6	0.7	1.4	0.8	0.7
" Na "	0.7	0.3	1.7	1.9	2.6
Sum of cations	29.2	29.5	43.1	28.9	32.3
Base sat. %, pH 8.2	53	60	83	71	94
ESP at pH 8.2	1	<1	3	5	8
Saturation extract:					
Moisture %					
pH-paste					
ECe (mS/cm)					

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	19.2
Mg "	8.0
K "	0.72
Na "	0.72
P (ppm)	32
Mn (me/100g)	0.60
Exch. acidity (me/100g)	
$pH-H_2O$ (1:1 v/v)	5.7
C %	2.01
N %	0.25

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	4-10	6.7	0.1
C1	20(15-25)	6.9	0.1
	40	6.8	0.4
C1	50-70	6.9	0.2
	70	7.1	0.2
	110	7.3	0.3
C2	110-130	7.2	0.2
C3	160(160-170)	7.4	0.2
	210	7.7	1.2
	260	7.9	0.8
	300	7.4	0.4
groundwater		7.4	2.0

Profile description no. 17

Observation/date	: P6; approx. 2 km east-northeast of Hewani turn-off; 28/9/'81
Maping unit	: B3 II SO
Physiography	: Floodplain; River basin land
Topography	: flat; moderate gilgai microrelief
Vegetation	: sedges
Salinity/sodicity	: non-saline ; non-sodic
Drainage conditions	: poorly drained; seanonally flooded up to 1.00 m; groundwaterlevel at 1.70 m

Profile description:

A_1	0-13 cm	black (10 YR2/1 moist); humic clay; moderate, very fine, subangular blocky structure; firm when moist, sticky and plastic when wet; few, fine, faint iron mottles; wavy transition to
C_1	13-90 cm	grayish brown (2.5 Y4/1 moist); clay; moderate, very fine, angular blocky structure; common, thin slickensides; sticky and very plastic when wet; common, medium, distinct iron mottles; common, fine roots up to 50 cm and few, fine roots extending to approx. 90 cm; gradual, wavy transition to
C_2	90-150 cm	dark grayish brown (2.5 Y4/2 moist); clay; moderate, medium angular blocky structure; abundant, thick slickensides; sticky and very plastic when wet; common, medium, distinct iron mottles; few (1%),fine (1 mm) manganese concretions; clear, smooth transition to
C_3	150-270 cm	dark grayish brown (10 YR4/2 moist); sandy clay; weak, coarse, angular blocky structure; few, thin slickensides; sticky and plastic when wet; common, medium iron mottles; few (1%), medium (3 mm) manganese concretions; many mica's; type of transition not observed because of augering from 170 cm onwards
C_4	270-300 cm	light olive brown (2.5Y5/4; sandy clay loam; sticky and slightly plastic when wet; many coarse, prominent iron mottles; many micas End of augering because of sand flowing into the auger hole

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 18

Observation no.: P8 Soil classification: vertic FLUVISOL

Mapping unit: B3 II So

Horizon	A11	A12	C1	C2	C3
Depth of sample (cm)	1-3	5-20	60-75	100-120	160-180
TEXTURE					
Sand % 2.0 - 0.05 mm	16	20	20	26	34
Silt % 0.05 - 0.002 mm	16	18	18	20	24
Clay % 0.002 - 0 mm	68	62	62	54	42
Texture class	C	C	C	C	C
CHEMICAL DATA					
pH-H_2O (1:2.5 v/v)	6.0	6.5	7.6	7.7	8.2
pH-KCl "	4.7	5.9	6.4	6.8	6.9
EC (mS/cm) "	0.4	0.55	2.1	1.3	0.65
$CaCO_3$ (%)					
$CaSO_4$ (%)					
C (%)	2.83	0.92	0.43	0.20	0.20
N (%)					
C/N					
CEC (me/100g), pH 8.2	42.6	33.4	38.6	34.2	33.6
Exch. Ca (me/100g)	14.1	14.1	15.0	15.0	9.4
" Mg "	7.3	10.1	17.3	16.9	18.1
" K "	1.4	0.6	0.3	0.3	0.3
" Na "	1.1	3.6	0.6	0.6	1.7
Sum of cations	23.9	28.4	33.2	32.8	29.5
Base sat. %, pH 8.2					
ESP at pH 8.2	3	11	2	2	5
Saturation extract:					
Moisture %				90.8	184.3
pH-paste				7.9	7.9
ECe (mS/cm)				6.1	4.5

FERTILITY ASPECTS: (depth in cm)	1-3	5-20
Ca (me/100 g)	15.2	12.1
Mg "	2.2	1.5
K "	0.04	trace
Na "	0.52	0.48
P (ppm)	35	7
Mn (me/100g)	trace	trace
Exch. acidity (me/100g)	0.1	
pH-H_2O (1:1 v/v)	5.4	6.3
C %	2.83	0.92
N %	0.29	0.11

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A11	2	5.6	0.5
A12	15	6.9	0.6
C1	60	7.8	0.4
C2	100	7.6	3.9
C3	170	7.5	2.5
groundwater	350	6.6	1.6

Profile description no. 18

Observation/date	: P8; approx. 5 km west from Lango la Simba and 0.2 km south from Garsen-Witu road; 28/3/'81
Mapping unit	: B3 II SO
Physiography	: Floodplain; River basin land
Topography	: flat; gilgai microrelief; few cracks, 4 cm wide, 30 cm deep
Vegetation	: grasses and some herbs
Salinity/sodicity	: non-saline to 80 cm, slightly saline onwards; non-sodic
Drainage conditions	: imperfectly to poorly drained; seasonally flooded; groundwaterlevel at 3.50 m

Profile description:

A_{11}	0-3 cm	dark reddish brown and black (5 YR3/3 and N2 moist); humic clay; strong, very fine angular blocky structure; firm when moist, sticky and plastic when wet; abrupt, smooth transition to
A_{12}	3-30 cm	black (N2 moist); clay; strong, fine angular blocky structure; firm when moist, sticky and plastic when wet; few, fine distinct iron mottles; many fine roots; abrupt, wavy transition to
C_1	30-80 cm	dark gray (10 YR4/1 moist); clay; strong, coarse prismatic structure, breaking into strong, medium, angular blocks; very firm when moist, very sticky and very plastic when wet; abundant, thick slickensides; common, fine, faint iron mottles; calcareous; few fine roots, mainly along peds; gradual smooth transition to
C_2	80-150 cm	dark grayish brown (10 YR4/2 moist); clay; moderate, coarse prismatic structure, breaking into moderate, coarse, angular blocks; few, medium slickensides; firm when moist, sticky and plastic when wet; common, fine, faint iron mottles; calcareous; few micas; clear, smooth transition to
C_3	150-230 cm	dark gray (10 YR4/1 moist); clay; weak, coarse angular blocky structure; few, thin slickensides; firm when moist, slightly sticky and plastic when wet; common, fine, faint iron mottles; calcareous; common micas; type of transition not observed because of augering from 200 cm onwards
C_4	230-280 cm	dark brown (10 YR3/3 moist); sandy clay loam; firm when moist, sticky and plastic when wet; common, fine, distinct iron mottles; slightly calcareous; few (2%), fine (2 mm) carbonate concretions; micas
C_5	280-330 cm	dark yellowish brown (10 YR4/4 moist); clay; firm when moist, sticky and plastic when wet; many, medium, distinct iron mottles; non calcareous; few (1%), fine (1 mm) carbonate concretions; micas
C_6	330-400 cm	dark grayish brown (10 YR4/2 moist); sandy clay; firm when moist, sticky and plastic when wet; common, medium, distinct iron mottles; micas
CG	400-500 cm	gray (5Y 5/1 moist); sandy clay with sandy layers; firm when moist, slightly sticky and slightly plastic when wet; common, coarse, distinct iron mottles; micas

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 19

Observation no.: P10

Soil classification: vertic FLUVISOL, sodic phase

Mapping unit: B3 II So

Horizon	A1	C1	C2
Depth of sample (cm)	0-20	60-70	150-160
TEXTURE			
Sand % 2.0 - 0.05 mm	20	20	42
Silt % 0.05 - 0.002 mm	6	8	18
Clay % 0.002 - 0 mm	74	72	40
Texture class	C	C	C/CL
CHEMICAL DATA			
pH-H_2O (1:2.5 v/v)	6.7	7.9	7.9
pH-KCl "	5.3	6.1	6.5
EC (mS/cm) "	0.60	0.50	0.80
$CaCO_3$ (%)			
$CaSO_4$ (%)			
C (%)	1.07	0.49	0.17
N (%)			
C/N			
CEC (me/100g), pH 8.2	34.6	42.6	23.6
Exch. Ca (me/100g)	19.2	3.2	7.6
" Mg "	12.3	17.5	4.9
" K "	0.47	0.31	trace
" Na "	1.12	3.76	0.50
Sum of cations	33.09	24.77	13.0
Base sat. %, pH 8.2	96	58	55
ESP at pH 8.2	3	9	2
Saturation extract:			
Moisture %			69.7
pH-paste			8.0
ECe (mS/cm)			2.10

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	14.5
Mg "	1.6
K "	0.04
Na "	0.55
P (ppm)	4
Mn (me/100g)	trace
Exch. acidity (me/100g)	
pH-H_2O (1:1 v/v)	6.1
C %	1.07
N %	0.10

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	20	7.2	0.6
C1	40	7.6	0.8
C1	70	7.9	1.2
C1	110	7.6	1.8
C2	170	7.5	1.4
groundwater	220	6.7	0.7

Profile description no 19

Observation/date	: P10; approx. 3 km south of Lango la Simba bridge; 27/3/'81
Mapping unit	: B3 II SO
Physiography	: Floodplain; River basin land
Topography	: flat; gilgai microrelief
Vegetation	: sedges on tussocks and some reeds
Salinity/sodicity	: non-saline ; sodic from 35 to 150 cm depth
Drainage conditions	: poorly drained; seasonally flooded during relatively long periods; groundwaterlevel at 2.20 m

Profile description:

A_1	0-35 cm	very dark gray (10 YR3/1 moist) and black (N2 moist); humic clay; strong, very fine, angular blocky structure; very firm when moist, sticky and very plastic when wet; few, fine, faint iron mottles along root channels; common, fine roots; clear, wavy transition to
C_1	35-150 cm	dark brown (10 YR4/3 moist); clay; moderate, coarse, prismatic structure; very firm when moist, sticky and very plastic when wet; abundant, thick slickensides; few (2%) medium (10 mm) carbonate concretions from 80 cm onwards; few, fine roots; gradual, smooth transition to
C_2	150-190 cm	brown (10 YR5/3 moist); clay loam to clay; moderate, fine angular blocky structure; firm when moist, sticky and plastic when wet; few, fine, faint iron mottles; few (2%), medium (10 mm) carbonate concretions and few (3%9, fine (2 mm) manganese concretions; some micas; no roots; gradual, smooth transition to
C_3	190-220 cm	yellowish brown (10 YR5/4 moist); fine sand; single grain; few, fine, faint iron mottles; many micas; clear, smooth transition to
C_4	220-260 cm	yellowish brown (10 YR5/6 moist); fine sand; single grain; no mottling; many micas End of auger observation at 260 cm due to sand moving into the auger hole

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 20

Observation no.: P12 Soil classification: vertic FLUVISOL

Mapping unit: B3 II So

Horizon	A1	C1	C2	C3	C4
Depth of sample (cm)	5-15	30-40	80-90	115-120	150-160
TEXTURE					
Sand % 2.0 - 0.05 mm	16	14	20	14	20
Silt % 0.05 - 0.002 mm	24	10	12	18	28
Clay % 0.002 - 0 mm	60	76	68	68	52
Texture class	C	C	C	C	C
CHEMICAL DATA					
pH-H_2O (1:2.5 v/v)	6.3	7.1	7.9	7.3	6.5
pH-KCl "	5.1	5.5	6.4	6.3	5.2
EC (mS/cm) "	0.55	0.65	0.90	4.00	0.60?
$CaCO_3$ (%)	0.16	0.13	0.17	0.03	0.17
$CaSO_4$ (%)	trace	tr.	tr.	0.96	0.12
C (%)	1.34	0.47	0.52	0.41	0.17
N (%)					
C/N					
CEC (me/100g), pH 8.2	36.0	49.4	55.0	51.0	41.5
Exch. Ca (me/100g)	21.0	28.0	32.0	35.0	24.0
" Mg "	17.3	14.0	19.5	24.0	24.0
" K "	1.1	1.2	1.2	1.0	0.8
" Na "	1.1	3.1	3.4	11.2	15.5
Sum of cations	40.5	46.3	56.1	71.2	64.3
Base sat. %, pH 8.2	>100	94	>100	>100	>100
ESP at pH 8.2	3	6	6	22	37
Saturation extract:					
Moisture %			103	95	
pH-paste			8.0	7.6	
ECe (mS/cm)			1.50	6.00	

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	11.2
Mg "	4.2
K "	0.27
Na "	0.46
P (ppm)	26
Mn (me/100g)	0.12
Exch. acidity (me/100g)	0.3
pH-H_2O (1:1 v/v)	5.2
C %	2.39
N %	0.25

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v pH	EC (mS/cm)
A1	10(5-15)	6.0	0.2
	20	6.6	0.1
C1	30-40	6.5	0.4
	70	7.3	0.7
C2	80-90	7.5	1.0
	110	7.4	2.5
C3	115-120	7.2	4.8
C4	160(150-160)	7.3	4.3
	300	6.9	5.5
	400	6.9	3.8
	500	6.9	2.6
groundwater		6.9	24

Profile description no. 20 (see also fig. 4.03)

Observation/date	: P12; approx. 4.5 km south of Garsen-Witu road and approx. 1 km west of Lango la Simba ; 6/10/'81
Mapping unit	: B3 II SO
Physiography	: Floodplain; River basin land
Topography	: flat; weak gilgai microrelief
Vegetation	: grasses and sedges on tussocks
Salinity/sodicity	: non-saline to 100 cm, moderately saline onwards; non-sodic
Drainage conditions	: poorly drained; seasonally flooded up to 1.00 m; groundwaterlevel at 1.00 m

Profile description:

A_1	0-18 cm	black (N2 moist); clay; weak, fine subangular blocky structure; few, thin slickensides; firm when moist, sticky and plastic when wet; many medium roots; gradual, irregular transition to
C_1	18-70 cm	very dark gray (N3 moist); clay; moderate, fine angular blocky structure; common, medium slickensides; firm when moist, very sticky and plastic when wet; common, fine,faint iron mottles; few (1%), fine (1 mm) manganese concretions; common, fine roots; clear,wavy transition to
C_2	70-103 cm	dark gray (5Y4/1 moist); clay; strong, fine angular blocky structure; abundant, thick slickensides; sticky and plastic when wet; common, fine, faint iron mottles; few (1%), fine (2 mm) manganese concretions; few, very fine roots; abrupt, smooth transition to
C_3	103-135 cm	dark grayish brown (10 YR4/2 moist); clay; strong, fine, angular blocky structure; abundant, thick slickensides; sticky and plastic when wet; common, fine, faint iron mottles; slightly calcareous; few (1%), fine (1 mm) manganese concretions; few (3%) medium (2-5 mm) carbonate concretions; abrupt, smooth transition to
C_4	135-170 cm	dark grayish brown (10 YR4/2 moist); clay; strong, fine, angular blocky structure; abundant, thick slickensides; sticky and plastic when wet; common, fine, faint iron mottles; few (1%) manganese concretions; slightly calcareous; type of transition not observed because of augering from 170 cm onwards
C_5	170-500 cm	dark grayish brown (10 YR4/2 moist); clay; firm when wet; common, fine, distinct iron mottles; few (1%), manganese concretions

LABORATORY DATA OF PROFILE DESCRIPTION NO.: 21

Observation no.: P18 — Soil classification: vertic FLUVISOL

Mapping unit: B3 II So

Horizon	A11	A12	C1
Depth of sample (cm)	15-20	45-55	130-135
TEXTURE			
Sand % 2.0 - 0.05 mm	16	20	20
Silt % 0.05 - 0.002 mm	32	14	28
Clay % 0.002 - 0 mm	52	66	52
Texture class	C	C	C
CHEMICAL DATA			
pH-H_2O (1:2.5 v/v)	7.3	7.3	8.0
pH-KCl "	5.8	5.8	6.6
EC (mS/cm) "	0.40	0.40	1.10
$CaCO_3$ (%)	0.10	0.07	0.96
$CaSO_4$ (%)	trace	0.14	tr.
C (%)	1.89	1.31	0.26
N (%)			
C/N			
CEC (me/100g), pH 8.2	52.0	55.2	48.9
Exch. Ca (me/100g)	29.0	24.0	27.0
" Mg "	24.0	14.0	12.0
" K "	1.1	0.9	0.8
" Na "	1.9	3.3	3.4
Sum of cations	56.0	42.2	43.2
Base sat. %, pH 8.2	>100	77	88
ESP at pH 8.2	4	6	7
Saturation extract:			
Moisture %			85
pH-paste			8.3
ECe (mS/cm)			1.85

FERTILITY ASPECTS: (depth in cm)	0-20
Ca (me/100 g)	18.8
Mg "	9.2
K "	0.90
Na "	1.06
P (ppm)	34
Mn (me/100g)	0.40
Exch. acidity (me/100g)	-
pH-H_2O (1:1 v/v)	5.6
C %	2.01
N %	0.30

FIELD LABORATORY DATA

Horizon	Depth (cm)	1 : 2.5 soil-water v/v	
		pH	EC (mS/cm)
A11	15-20	7.2	0.2
	20	7.1	0.2
	40	7.0	0.4
A12	45-55	7.1	0.5
	70	7.4	0.7
	110	8.0	1.0
C1	130	8.0	1.4
	160	7.5	5.0
	280	7.3	6.0
	360	7.2	5.0
	470	7.2	5.0
groundwater		7.0	2[illegible]

Profile description no. 21

Observation/date	: P18; approx. 4 km south-east of Gomessa; 3/10/'81
Mapping unit	: B3 II SO
Physiography	; Floodplain; River basin land
Topography	: flat; moderate gilgai microrelief
Vegetation	: grasses and some sedges
Salinity/sodicity	: non saline; non sodic
Drainage conditions	: poorly drained; seasonally flooded up to 1.00 m; groundwaterlevel at 2.50 m

Profile description:

A_{11}	0-30 cm	black (N2 moist); humic clay; moderate, fine, subangular and angular blocky structure; few, fine, thin slickensides; firm when moist, sticky and plastic wet; common, fine roots; gradual, smooth transition to
A_{12}	30-70 cm	black (10 YR2/1 moist); clay; moderate, fine to very fine angular blokcy structure; common, thick slickensides; firm when moist, sticky and plastic when wet; few, very fine roots; clear, wavy transition to
C_1	70-180 cm	dark grayish brown (10 YR4/2 moist); clay; moderate, medium angular blocky structure; commom, thick slickensides; firm when moist, very sticky and plastic when wet; common, fine, distinct iron mottles; few (1%), fine (2 mm) and manganese and few (1%), medium (2-5 mm) carbonate concretions; type of transition not observed because of augering from 180 cm onwards
C_2	180-250 cm	dark gray (5Y4/1 moist); clay; firm when moist, very sticky and plastic when wet; common, fine, distinct iron mottles; few (1%), fine (2 mm) manganese concretions
C_3	250-320 cm	brown (10 YR4/3 moist); clay; firm when moist, very sticky and plastic when wet; common, fine distinct iron mottles; few (1%), fine (2 mm) manganese concretions
C_4	320-400 cm	gray (5Y5/1 moist); clay; firm when moist, very sticky and plastic when wet; few, fine, faint iron mottles; few (1%), manganese concretions
C_5	400-430 cm	gray (5Y5/1 moist); sandy clay loam; friable when moist, sticky and non plastic when wet; common, medium, distinct iron mottles; few (1%), manganese concretions
C_6	430-500 cm	dark grayish brown (10 YR4/2 moist); clay; firm when moist, sticky and plastic when wet; many, medium, distinct iron mottles; few (1%), manganese concretions

APPENDIX 2

Data of the reconnaissance soil survey

Table A2.1 Legend of the reconnaissance soil map

F... FLOODPLAINS

FR.. Soils developed on recent fluvial sediments

FRl. River leveeland

- **FRl1** complex of sand to clay, often stratified; excessively to imperfectly drained; usually non-calcareous and non-saline; often rich in micas (eutric and vertic FLUVISOLS)
- **FRl2** complex of loam to clay, stratified; well to imperfectly drained; often calcareous and saline (eutric and vertic FLUVISOLS)
- **FRl3g** dark grayish brown, cracking clay; moderately well to imperfectly drained; usually non-calcareous and non-saline; grassland (vertic FLUVISOLS)
- **Frl3b** like FRl3g; but wooded bushland
- **FRl3f** like FRl3g; but woodland

FRb. River basinland

- **FRb1** 10-20 cm very dark gray, humic clay over dark brown, cracking clay; moderately well to imperfectly drained; usually non-calcareous and non-saline (vertic FLUVISOLS)
- **FRb1f** like FRb1; but woodland
- **FRb2** 10-20 cm very dark gray, humic clay over dark brown, cracking clay; imperfectly drained; usually non-calcareous and non-saline (vertic FLUVISOLS)
- **FRb2f** like FRb2; but woodland
- **FRb3** 20 cm very dark gray, humic clay over dark grayish brown, cracking clay; poorly drained; usually non-calcareous and non-saline (vertic FLUVISOLS)
- **FRb3f** like FRb3; but woodland
- **FRb4** 10-20 cm dark gray, humic clay over dark grayish brown, cracking, fluvial clay, between 50-150 cm overlying marine clay or silty clay; imperfectly to very poorly drained; non-calcareous; deeper than 100 cm strongly to extremely acid (catclay); slightly to moderately saline within 100 cm; deeper than 150 cm locally unripened (vertic FLUVISOLS, saline phase)

FE.. Soils developed on subrecent marine sediments

FEl. Recent leveeland

- **FEl1** 30-100 cm grayish brown, cracking, fluvial clay over extremely acid, marine clay (catclay); imperfectly drained; non-calcareous; non-saline within 100 cm (vertic and thionic FLUVISOLS)

FEb. Basinland

- **FEb1** complex of:
  - 10 cm black, humic to peaty clay over very dark gray clay, between 30-50 cm overlying extremely acid clay (catclay), locally within 150 cm changing into neutral to slightly acid sandy clay to loamy sand; poorly drained; non-calcareous; moderately saline from 30-50 cm depth onwards (thionic FLUVISOLS, saline phase)
  - 10 cm black, peaty clay over very dark gray clay, between 50-150 cm overlying strongly to extremely acid clay (catclay); very poorly drained; non-calcareous; moderately saline from 50-100 cm depth onwards (eutric and thionic FLUVISOLS, saline phase)
- **FEb2** 10 cm black, humic clay over very dark gray clay, within 100 cm overlying gray clay, locally deeper than 100 cm changing into sand; imperfectly to very poorly drained; non-calcareous; slightly acid or slightly acid over extremely acid; non- to slightly saline (eutric and thionic FLUVISOLS)

T... TERRACE LAND

TO. Soils developed on old alluvial sediments

- **TOu** undifferentiated (orthic and vertic SOLONETZ and pellic VERTISOLS)
- **TOb** soils of the bottomlands, adjacent to and in connection with the floodplains; very poorly drained (pellic VERTISOLS, partly saline phase)

B. FORMER BEACH RIDGES

BQ Soils developed on sandstone and beach deposits

- **BQ** undifferentiated (ferralic ARENOSOLS and orthic FERRALSOLS)

C. COMPLEX AREAS

CF Soils developed on recent alluvial and old alluvial sediments

- **CF** complex of:
  - mapping units FRb1, FRb2 and FRb3, often over old alluvial sediments
  - mapping unit TOu

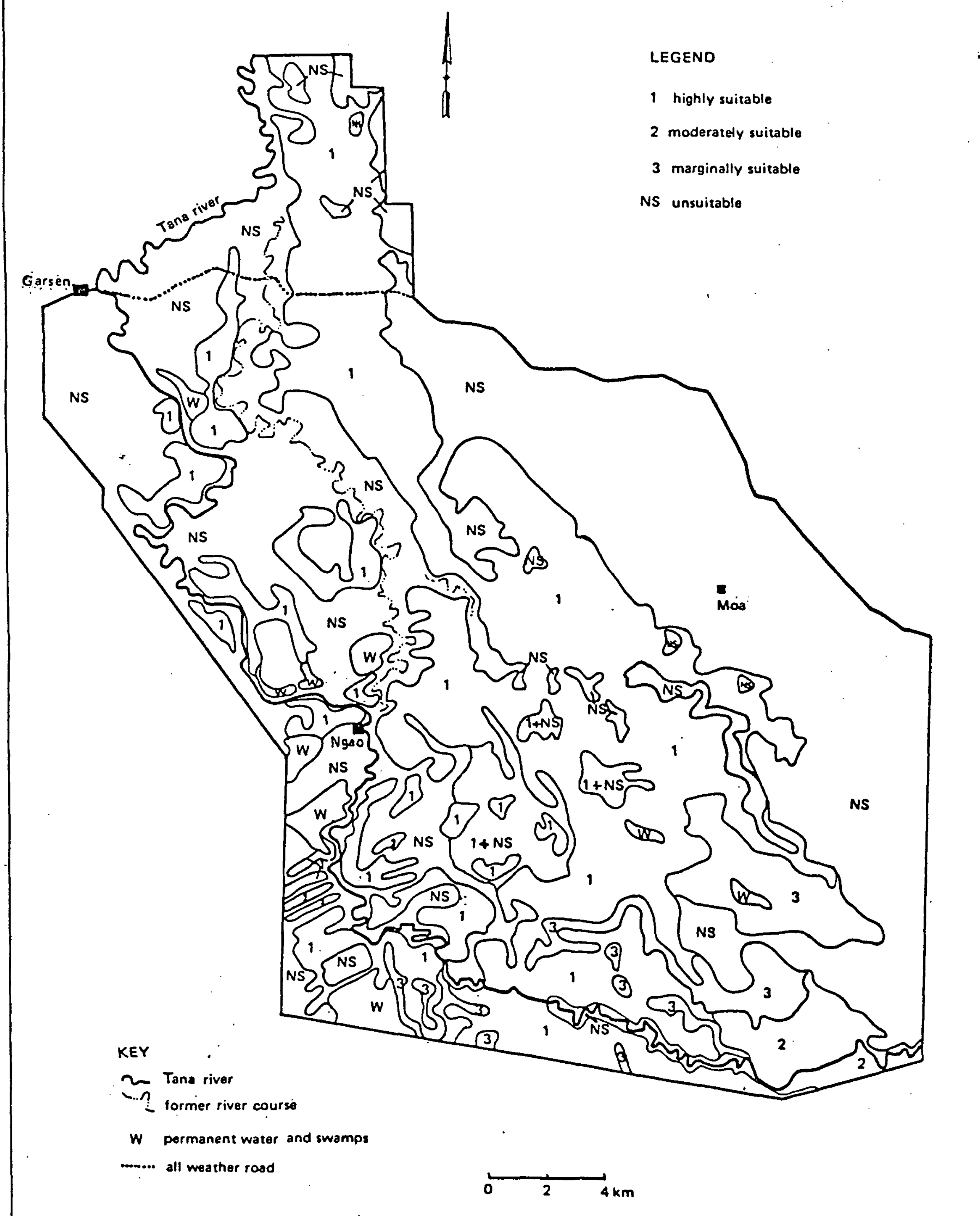
Table A2.2

Main landcharacteristics and landsuitability classes of the mapping units for large scale irrigated rice, not considering irrigability and drainability.

		Mapping unit	Soil texture	Soil permeability when wet	Soil reaction ($pH - H_2O$)	Soil salinity	Relief: macro; relative height	Relief: meso	Relief: micro	Vegetation type	Landsuitability classes	Acr…
RECENT FLUVIAL SEDIMENTS	RIVER LEVEELAND	FRl1*	deep, complex of sand to clay; stratified	slow to rapid	6,5 - 8,4	non-saline	flat to gently undulating; moderately high, in places high	locally very irregular, due to presence of abondoned river courses	-	grassland, bushed grassland, woodland and patches of riparian forest	NS stf (....f only locally)	759
		FRl2*	deep, complex of loam to clay; stratified	slow to moderately rapid	6,5 - 8,4	slightly saline	flat to gently undulating; moderately high	locally very irregular, due to presence of abondoned river courses	-	riparian forest	NSstf (....f only locally)	52
		FRl3g	deep, cracking clay	slow	6,5 - 8,4	usually non-saline; locally moderately saline from 50 cm onwards	flat; moderately high	-	gilgai	grassland, bushed grassland	1	76
		FRl3b*	deep, cracking clay	slow	6,5 - 8,4	usually non-saline	flat to very gently undulating; moderately high	comprises small (levee) ridge with former river course	-	wooded bushland, bushland	3tf	1050
		FRl3f	deep, cracking clay, locally over loamy sand	slow	6,5 - 8,4	non-saline	flat to very gently undulating; moderately high	with wide former river course	-	riparian forest	NStf	340
	RIVER BASINLAND	FRb1*	deep, cracking clay	slow	6,0 - 8,0	non-saline	flat; moderately high	-	gilgai	grassland, bushed grassland; locally doumpalms	1	5000
		FRb2*	deep, cracking clay	slow	6,0 - 8,0; locally in subsoil 8,5 - 9,4	non-saline; locally slightly saline from 100 cm onwards	flat; moderately low	locally depressions	gilgai, small humps in depressions	grassland, locally bushed grassland; grasses and reeds	1	8060
		FRb3*	deep, cracking clay	slow	5,8 - 7,5	non-saline; locally slightly saline from 100 cm onwards	flat; low	locally gullies	gilgai, tussocks up to 50cm height	grassland; grasses and sedges or reeds	1	10350
		FRb4	deep, cracking clay	slow	4,8 - 6,5; starting at approx. 50 cm depth 4,0-5,0 locally <4,0	non-saline; slightly to moderately saline from 50 cm onwards	flat; low and moderately low	irregular, due to presence of small, shallow gullies	gilgai on higher parts, cowfoetoes in gullies	grassland; reeds and herbs	3 st	2130
SUBRECENT MARINE SEDIMENTS	[illegible] LEVEELAND	FEl1	deep, clay	slow	5,0 - 7,0 deeper than 30-100 cm 3,5 - 4,5	non-saline; deeper than 100 cm moderately saline	flat; moderately low	with present Tana river bed	-	grassland; scattered doumpalms	2s	280
	BASINLAND	FEb1	-deep usually clay, locally within 150 cm depth overlying sandy clay to loamy sand -deep, clay	slow slow	4,8 - 6,0; starting at 30-50cm depth usually 3,0-4,0 5,0 - 5,0 starting at 50-100cm depth usually 3,0-4,0	-non to slightly saline; usually moderately saline from 30-50 cm onwards. -moderately saline from 50-100cm onwards	flat; low	irregular, due to presence of wide, shallow gullies	weak gilgai	grassland; mainly reeds	NSst	4250
		FEb2	deep, clay, locally deeper than 100 cm changing into medium fine sand	slow	5,5 - 7,0; locally deeper than 100 cm 3,5 - 4,5	usually non-saline; locally deeper than 100 cm slightly saline	flat; low	irregular, due to presence of wide, shallow gullies and depressions	cowfoetoes in gullies and depressions	grassland; reeds and grasses	2t	1170
OLD ALLUVIAL SEDIMENTS		TOu*	predominantly: -topsoil of loamy sand to sandy clay over cracking clay -topsoil of loamy sand over sandy loam to sandy clay loam	slow	-usually >9,0 - >8,5	-non-saline -usually non-saline over saline to strongly saline	very gently undulating to flat; high	-	-	bushland, bushland thicket, grassland -bushland thicket	NSu	17100
		TOb	deep, cracking clay	slow	6,0 - 7,5; locally 4,0 - 5,0	usually non-saline; locally strongly saline	flat; low		gilgai, humpy	grassland	1 + NSs	1050
SANDSTONE AND BEACH DEPOSITS		BO*	deep, sandy clay loam to sand	moderate to rapid	<5,0; locally >6,0 in topsoil and >8,5 in subsoil	non-saline; locally saline in subsoil	flat to undulating	low ridges	-	bushland, bushland thicket	NSsf	2340
RECENT FLUVIAL AND OLD ALLUVIAL SEDIMENTS		CF	complex of: -mapping unit FRb1, FRb2, FRb3 -mapping unit TOu	slow	5,8 - 8,0; locally >8,5 -	non-saline; locally slightly to moderately saline from 100 cm onwards	flat to very gently undulating	irregular, due to presence of many, small outcrops of mapping unit TOu	-	grassland, bushed grassland, bushland	1 + NSst	1520

*mainly based on information in "Detailed reconnaissance soil map (sheet 2)" of the Lower Tana Village Irrigation Programme.

*Small areas of the mapping units FRb1, FRb2 and FRb3 are covered with woodland or riparian forest. They are distinguished on the soil map with the symbol ....f. These areas, in total approx. 150 ha, are classified as unsuitable (class NStf) in the detailed reconnaissance survey of the LTVIP.



HASKONING bv

Mwenge International Associated Limited

fig: 5.02

title: GENERALIZED LAND SUITABILITY MAP OF THE RECONNAISSANCE SURVEY